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Technology in health care logistics

A PhD thesis by Pelle Jørgensen

PhD Thesis at the Technical University of Denmark

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Dansk resumé

Hospitaler i det meste af den industrialiserede verden står overfor en kæmpe udfordring i de kommende år, der skal leveres mere sundhed for de samme penge. Den demografiske udvikling og den øgede andel af befolkningen i en mere sundhedskrævende alder resulterer i at der skal håndteres en langt større patientmasse end tidligere. Det er derfor afgørende, at hospitalerne effektiviseres for at leve op til kravet om at levere mere sundhed for de samme eller færre penge. Et af de mest omkostningstunge områder på hospitaler er logistikken, og studier har vist, at mere end 30 % af de samlede hospitalsomkostninger relaterer sig til logistik omkostninger. Det er derfor muligt, at finde store potentielle effektiviseringspotentialer indenfor logistik. Logistik på hospitaler står imidlertid overfor to problemer. 1) Logistik på hospitaler er tidligere blevet håndteret ved at tage udgangspunkt i afdelingerne, hvilket har resulteret i at logistikken er blevet suboptimeret. 2) I industrien er teknologi i høj grad blevet brugt til at optimere og forbedre forskellige logistikske systemer. Dette har ikke i samme omfang været tilfældet indenfor sundhedssektoren, og der findes derfor et stort potentiale i at bruge teknologi til at forbedre logistikken. På hospitaler er teknologi i langt højere grad blevet brugt indenfor kliniske områder.

Baseret på disse udfordringer præsenterer forskningsprojektet en analytisk model, der kan benyttes til at analysere logistiske systemer på hospitaler og sikrer, at hele systemet anskues, også systemer der involverer flere afdelinger. Som en del af modellen er et performance målings værktøj blevet konstrueret, der måler performance af det logistiske system, hvilket gør det muligt at fastslå, hvor systemet performer dårligt. Yderligere gør modellen og værktøjet det muligt at finde og vurdere forskellige teknologiske løsninger, der kan benyttes til at forbedre og effektivisere det eksisterende system. Den analytiske model og performance målings værktøjet gør det dermed muligt for hospitalsledelsen, at analysere de forskellige logistiske systemer og få et indblik i hvor implementering af ny teknologi vil have størst effekt. Samtidig gør modellen det muligt kontinuerligt at vurdere de logistiske systemer og dermed sikre en løbende forbedring og effektivisering af hospitalet. Som en konsekvens af projektet er ny teknologi blevet implementeret for en case og implementeringen er i den indledende fase for andre cases.

Afhandlingen er bygget op omkring seks videnskabelige artikler, og de vigtigste bidrag og konklusioner fra artiklerne præsenteres i afhandlingen. Artiklerne præsenterer udviklingen af resultaterne i løbet af projektet, og hvordan disse er blevet udviklet og tilpasset, efterhånden som modellen er blevet testet og valideret. Artiklerne består af tre artikler præsenteret på videnskabelige konferencer, og tre artikler fremsendt til videnskabelige tidsskrifter. Foruden resultaterne fra artiklerne præsenterer afhandlingen en detaljeret beskrivelse af den videnskabelige tilgang benyttet, og hvilke overvejelser der har været i relation til den videnskabelige tilgang og de opnåede resultater.

Summary

In most of the developed countries hospitals are facing a major challenge – they have to provide more health care using the same resources. Due to the demographic trend and the increasing share of the population being in a more health-demanding age, the hospitals will have to deal with more patients in the future. It is therefore essential that the hospitals are more efficient in order to meet the requirement of providing more health for the same or less resources. Studies have shown that more than 30% of hospital expenditures are related to various logistics cost, making the logistics an area with huge efficiency potential. However, hospital logistics are facing two problems. 1) Hospital logistics have to a large extent been dealt with using a departmental approach resulting in sub-optimised logistics. 2) In industry, the use of different technological solutions to perform and control the logistical processes is very common. This has however not to the same extent been the case within hospitals, where technology primarily has been used within the clinical settings. There is therefore a large potential in using technology to improve the logistics.

Based on these considerations the research presents an analytical model that can analyse the logistical system using a holistic approach, and explore the possibility of using technology to improve the current system. A logistical system is one of the different flows happening at a hospital. Included in the analytical model is a performance assessment tool, which has been designed to assess the performance of the logistical system, thereby pinpointing where the system is performing poorly. Additionally the model and tool makes it possible to evaluate various technologies that can be used to improve and optimise the existing system. The analytical model and performance measurement tool thus makes it possible for the hospital management to analyse the various logistical systems, and gain an insight of which parts of the logistical system will have the largest benefit from implementing new technology. Concurrently the model makes it possible to continuously assess the logistical systems in order to ensure continuous improvement and efficiency of the hospital. As a consequence of the project new technologies have been implemented in one case, and implementing technology is in the preliminary phases for other cases.

The thesis is based on six scientific articles, and the main contributions and conclusions from the articles are presented in the thesis. The articles present the development of the results throughout the study, and how the results have been adjusted and adapted, as the model was tested and validated. The articles consist of three papers presented at scientific conferences, and three articles submitted to scientific journals. In addition to the results, the thesis presents a detailed description of the scientific approach taken, as well as considerations in relation to the scientific approach and the achieved results.

Preface

This dissertation is submitted to DTU Management Engineering, Technical University of Denmark, in fulfillment of the requirements for acquiring the PhD degree. The work has been supervised by Associate Professor Peter Jacobsen. The dissertation consists of a recapitulation of the research study and a collection of six research papers prepared during the period from June 2010 to May 2013. Generally, British spelling rules are used in this thesis. All the thesis publications have been submitted under the name `Pelle Jørgensen`.

Pelle Jørgensen, Kgs. Lyngby, May 2013

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My PhD project would not have been possible if it wasn't for some very helpful people, and I would like to take the opportunity to send my deepest appreciation to you.

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Chapter 1 – Introduction

This chapter aims to provide insight into the foundation of the research, which was initiated due to the need for a tool capable of analysing hospital logistical systems, in order to improve such systems by implementing new technology in a systematic manner. The chapter presents the background for the need to develop such a tool, as well as some of the overall considerations in the health care sector today and how these considerations are experienced on a daily basis. The theoretical framing of the research is then presented together with some of the literature within the area of health care technology and logistics. The chapter concludes by presenting some key concepts of the research.

1.1 Challenges in health care

In the years to come, health care will be facing increasing challenges. The first round of baby boomers turned 65 in 2011. As a result, the developed countries face a situation where the ratio of people needing care to the people providing health care will change dramatically (OECD 2011). Concurrently, the financial crisis has resulted in increased focus on health care institutions' budgets with the aim of reducing expenditures. Accordingly, modern health care is characterized by increasing demands for individualized high quality services, and rapid development of health care technologies, all resulting in increased pressure on hospitals. In Denmark, a health care reform has been implemented in order to cope with these challenges. One of the major outcomes of the Danish reform is that hospitals are currently being changed radically, and new hospitals are being constructed (Andersen & Jensen 2010). One result of the changes is increased focus on how to engineer the logistics more efficiently. Studies show that 30-46% of health care expenditures relate to various health care logistics (Poulin 2003), and 31% of health care providers' operational costs are spent within the health care supply chain (Nachtmann & Pohl 2009). Hence, the demand for monitoring and improving logistics is increasing. One important area in this context is utilizing the technological possibilities for optimizing logistical systems, and thereby maintain the same health service level with less medical personnel at a lower cost.

Hospitals are large complex organisations consisting of many different departments. Treatment of patients often involves several departments that are either directly involved in treatment (e.g. emergency or surgery wards) or indirectly involved (e.g. laboratory, cleaning and sterilization departments). Therefore, many different hospital logistical systems are connected with patient services. The primary approach to solving the in-house logistical challenges has been a departmental (horizontal) view, which thereby lacks the holistic view of the entire in-house logistical system (vertical). This has led to sub-optimisation of the logistical system (Mayfield 2009, Shumaker 2007). Consequently, the need exists for a holistic tool that is capable of analysing hospital logistics in order to pinpoint poor performance in the current setup.

One of the major Danish hospitals, Herlev Hospital, faces these challenges. The hospital has identified three issues that need to be dealt with in order to cope with the challenges. The first issue is that internal logistics involving many different departments should be dealt with in a horizontal and holistic manner. The second is that technology should be used to improve logistics to a larger extent than is currently the case. Finally, while the main use of technology in health care has been related to the clinical areas and treatment of patients, there is a need for greater focus on using technology to improve other areas within health care.

Herlev Hospital's perception was that some research addressed the issues individually but not all three issues concurrently, which was what was needed. The aim of the research is therefore to meet the challenge of creating a tool that could analyse the logistical system using a holistic approach, and to explore the possibility of using technology to improve the current system.

1.2 Technology and logistics

The terms *technology* and *logistics* have different meanings depending on the perception of the terms. In this research project, the definition of technology is taken from Britannica Online (2013a): "...the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment." Based on this definition, technology is seen as the ability to implement or use measures that can help employees carry out a process in a more automated and less manual manner. Technology has been used throughout human history, from the various primitive tools used to capture and kill animals for eating, to the development of the steam engine, and to the most modern computer technologies such as smart phones and tablets. Using different types of technology, changing existing technologies and inventing new types of technology have been very important in the quest to do things more efficiently and in an improved way.

The definition of logistics given by Britannica Online (2013b)is: "...the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements." Logistics and logistical systems are extremely important to any organisation. All organisations have logistical systems, although the items being transported are very different. Logistics can involve information used in a service organisation, raw material to be used in a production facility or the final goods from production. In addition, logistics can involve tools or instruments used to perform different tasks or processes.

Combining the two terms into *using technology within logistics* reflects the perception of a way to achieve higher efficiency and service by making changes in the flow of goods, services, and related information by using products and services created through the application of scientific knowledge. Introducing Operations Management and LEAN thinking into this context provides the scope to create a systematic approach toward improving the logistical systems by utilizing new technological possibilities.

Technology in logistics – material-handling technologies

In addition to solving many daily problems, technology has been used to a large extent to make logistical processes faster and more efficient. Often, the ultimate goal of using technology within logistical systems is to automate logistics completely, so that humans are not involved in performing the logistical processes but merely in supervising and controlling the processes. Different degrees of automation of the logistical processes can be found between completely manual transportation and full automations, as shown in figure 1. A logistical process can be analysed and placed on this scale, making it possible to determine whether it is possible to further automate the process.

Automation scale

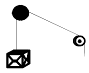
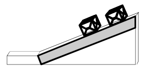
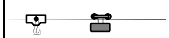
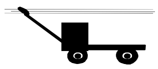
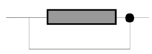
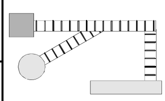
Classification		Grade	Description	Example	Characteristics
Manual control	Manual power	1.	Manual work		Human carry the goods
Manual control	Manual power	2.	Manual equipment		Equipment carry the goods
Manual control	Manual power	3.	Mechanical equipment, manual operated		Movement with mechanical devices
Manual control	Gravity	4.	Gravity driven equipment		Compulsory control of materials
Manual control	External energy	5.	Energy driven, manual control		Equipment works human controlled
Manual control	External energy	6.	Energy driven, remote control		Control by remote control
Automatic control	External energy	7.	Energy driven, software control		Control by a program
Automatic control	External energy	8.	Energy driven with feed back		Automatic corrections based on signals
Automatic control	External energy	9.	Self adjusting equipment		Integrated system, signals and activities
Automatic control	External energy	10.	Full automatic system		

Figure 1: Automation scale for logistical processes (Jacobsen 2008)

In industry, it is very common to use different technological solutions to perform and control the logistical processes. The field of material handling deals with how production facilities should be constructed, and how different technologies can be used to manage the transportation and handling of different logistical processes (Tompkins 2010). Material handling occurs continuously within the life cycle of a product. Initially, there is the handling of raw materials, assembling of different parts, storage of material, transportation of material etc. Accordingly, material handling is very important at hospitals. The primary material handling processes are related to receiving items, storing items and transporting them to departments. The different types of material handling devices used can be systematized by dividing them into three different types, depending on the area or path of the transportation. The first group of material handling devices is related to conveyors, which are used to transport the material through a fixed area/path. Different technologies used within this group are belts, pneumatic tubes, chains etc. The second group of devices is related to cranes, which perform transportation over a limited area. Examples are cranes, hoists etc. The last group of devices is related to trucks and transportation over a wide area.

Different types of technologies within this group are powered trucks, automated guided vehicles etc. (Diaz & Smith 2008).

Technology in health care

Technology plays a crucial role in patients' treatment and recovery. All treatments and operations use to a very large extent different types of technology, from diagnostic to advanced surgical tools. As a consequence of this wide use of technology, extensive research focuses on improving the care and treatment of patients through developing new technologies as well as innovating existing ones. By exploring research conducted within technology and health care, five major focus areas were identified.

The first major area is concerned with *new technological methods* to improve patient treatment and diagnostics. This part of the literature focuses mainly on new technological possibilities and inventions made on the basis of various clinical results. The main part of this research is conducted with regard to new technologies to be used in treatment and surgery (Bowater et al. 2011, Barbash & Glied 2010, Carlsson et al. 2010, Stein 2009). Additional research conducted within this area regards testing new types of diagnostics (Balambigai & Asokan 2011) and investigating how to improve health care in general (Spear 2005).

The second focus area in the literature is *telemedicine* and its possibilities. Telemedicine is gaining increasing focus, with journals dedicated entirely to this area (e.g. *Journal of Telemedicine and Telecare*, and *Telemedicine and e-Health*). Telemedicine is divided into two main research areas: 1) monitoring patients at home (Brennan, Mawson & Brownsell 2009, Masella & Zanaboni 2009, Polisena et al. 2009, Chau & Hu 2004, Menachemi, Burke & Ayers 2004); and 2) conducting long-distance surgery or treatment (Okamura, Matarić & Christensen 2010, Brennan, Mawson & Brownsell 2009, Berlinger 2006, Mendez et al. 2005, Chau & Hu 2004, Gagnon et al. 2003).

The third major area is within *ICT* (Information and Communication Technology). The primary focus is how to digitalize and control patient data (Issel et al. 2011, Spil et al. 2011, Bogner 2010, Xiao et al. 2010, Thompson & Dean 2009, Lanseng & Andreassen 2007, Devaraj & Kohli 2000, Herriott 1999).

The fourth area of focus is *technology assessment*. Here, the focus is on how to gain the best impact from implementing different types of technologies. The focus is on technologies used in treatment and surgery (Kidholm et al. 2012, Sampietro-Colom et al. 2012, Johnson et al. 2009, Thielst 2007, Neumann & Blouin 1999).

The last area of focus is on the use of different types of *robots* in health care. This area is also closely related to the development of new types of technologies to be used in treatment and diagnosis. The focus is on how robotics can help in patient treatment and surgery (Okamura, Matarić & Christensen 2010, Nejat, Sun & Nies 2009, Stein 2009, Matarić et al.

2007), and also on some of the ethical issues that arise with the increasing use of robots (Coeckelbergh 2010, Sharkey 2008).

Exploring the literature on technology in health care revealed that much focus is on using technology in order to improve health care. The literature review showed that the focus almost entirely is on the use of technology within clinical areas, which substantiates the importance of a call for research in technology assessments within health care logistics.

Logistics in health care

Hospitals require many different types of logistics, but the logistics with the most focus involves patients. Investigating the literature with regard to logistics in health care revealed six major areas with the most focus.

Probably the best-researched area with the most focus in the popular media is *LEAN* in health care. LEAN has been seen by some hospital professionals as the solution to improving and optimizing hospitals and hospital logistics. Much of the research conducted within LEAN in health care has been related to case study research (Dickson et al. 2009, Banerjee, Mbamalu & Hinchley 2008, King, Ben-Tovim & Bassham 2006, Spear 2005), but some theoretically founded research has also been published (Souza 2009).

Another area that has also had much focus is the hospital's *supply chain*. Much of this research focuses on how to improve procurement at health care institutions (Vries & Huijsman 2011, Logan et al. 2010). However, the main focus within this area is how to improve and optimize the supply chain (Dooley 2009, Sinha & Kohnke 2009, Birk 2008, Lapierre & Ruiz 2007, Pan & Pokharel 2007, Jarrett 2006, King 2004, Poulin 2003).

The third area of focus has been on the use of *RFID chips* and *logistical tracking devices*. The importance of documenting processes and tracking all items used in patient treatment is based on the aim to improve treatment quality and ensure patient safety (Poland et al. 2011, Awami et al. 2009, Florentino et al. 2008, Pan & Pokharel 2007).

The fourth focus area, the *flow of patients,* has also been researched extensively. Some of the research within this area is related to the research on LEAN in health care. The aim of this research is to create a more efficient patient flow in order to improve treatment quality (Fitzgerald 2011, Vermeulen et al. 2009, Vissers & Beech 2005).

A fifth area of research is the *structuring of hospital departments* and how to *construct and design the hospital* with regard to the departments (Oddoye et al. 2009, Espinosa, Case & Kosnik 2004). The goal of the research is to make a better patient flow (Villa, Barbieri & Lega 2009) as well as ensure optimal working routines for the employees (Norrish & Rundall 2001).

Finally, the use of simulation and mathematical modelling is gaining increasing recognition within the health care sector. Simulation is used as a means to analyse processes within hospitals and test the impact of making different changes (Gunal 2012, Brailsford et al. 2009, VanBerkel & Blake 2007).

Exploring the literature regarding logistics in health care showed that there is focus on improving the logistics. The literature survey showed that it was mainly the literature dealing with RFID chips and tracking devices that exploited the potential of using technology to improve logistics.

Using technology in logistics within health care

Based on the literature survey regarding technology and logistics in health care, it became apparent that although both areas have been heavily researched, the literature lacks research regarding using technology to improve logistics. In the initiation of the project this was also the perception of the hospital management at Herlev Hospital. When this project was initiated, Herlev Hospital was starting a process to transform its approach to hospital logistics. Hospital logistics became a core focus of the hospital in order to make the hospital more efficient and improve patient treatment. As a consequence of this new focus, emphasis was placed on the use of technology as the driver to make logistics more efficient. It was found through searching the existing literature that this particular area had not received particular focus. The hospital was therefore very interested in a model capable of improving logistics. The combination of Herlev Hospital's need for a model for exploring technological possibilities for improving logistics, and the lack of such a model, laid the foundation for the project.

Prior to the research project, Herlev Hospital had worked with technology implementations in different settings. They worked with the notion that implementing new technologies within hospital settings had an impact on the structure and procedures of the operational setting. In addition, they used education as the driver to make sure that the technology was implemented correctly and that the structure and procedure is in line with the technology. The combination of Herlev Hospital's approach and the literature survey led to the development of the theoretical foundation of the research – that in order to make a change to the system, changes need to be made in either the logistics, technology, structure or procedure (figure 2). Also, changes within one area will affect the other areas.

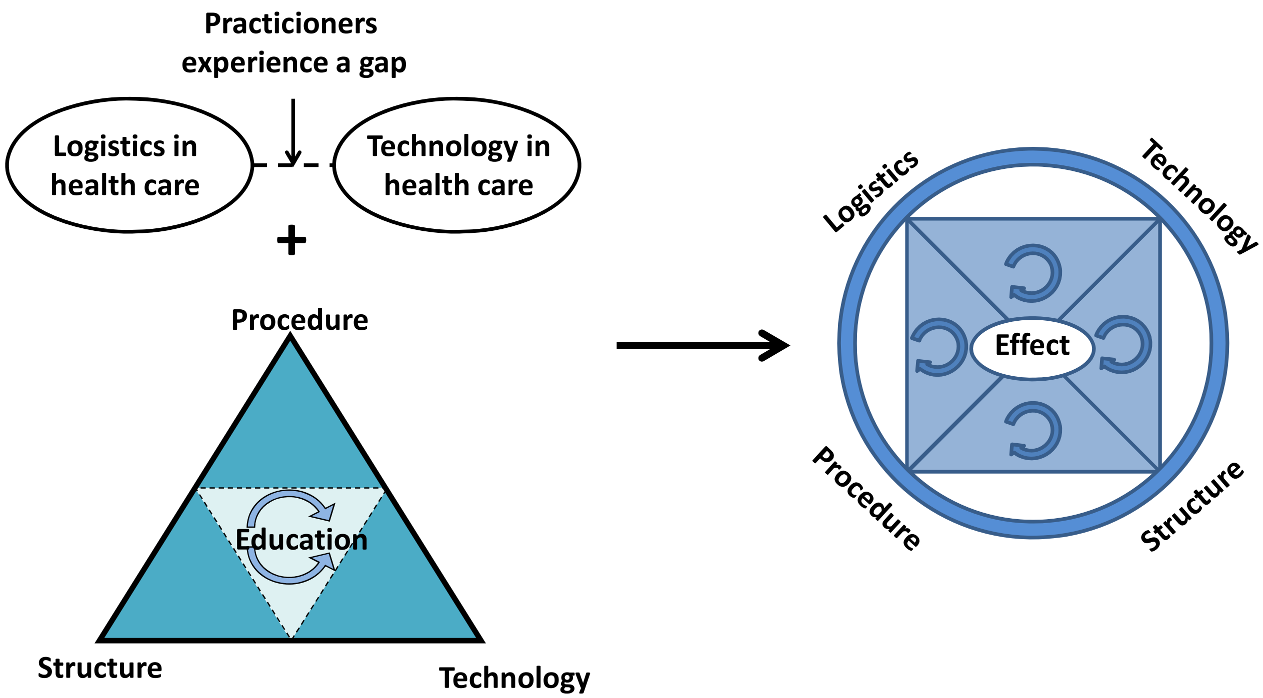


Figure 2: Development of the theoretical foundation – combination of Herlev Hospital's approach to technology implementations and the gap in the literature

1.3 Logistical systems at hospitals

One of the key concepts of this research is logistical systems. It is very important to have a full understanding of what is meant by this term in order to have complete insight into what logistics it is exactly that is in focus. At hospitals, there are many different logistical systems. The main flow is the patient flow. In order to make the patient flow function optimally, three types of different flows or logistical systems are initiated to secure its execution. The three flows are 1) a resource/employee flow, 2) an information flow, and 3) a supporting flow. The resource/personnel flow focuses on the resources and employees available to perform the treatment process. The information flow relates to the information generated in the execution of the process. The supporting flow is the flow of items and materials used in relation to the patient flow but not directly involving the patient. As its name indicates, it supports the patient flow (see figure 3). Supporting flows can be considered as back-office processes; they are essential for making the front-office processes (patient treatment) function. The supporting flows can include the transportation of many different items and tools. Examples can be such items as equipment to be used in relation to treatment, medication, food, linens etc.

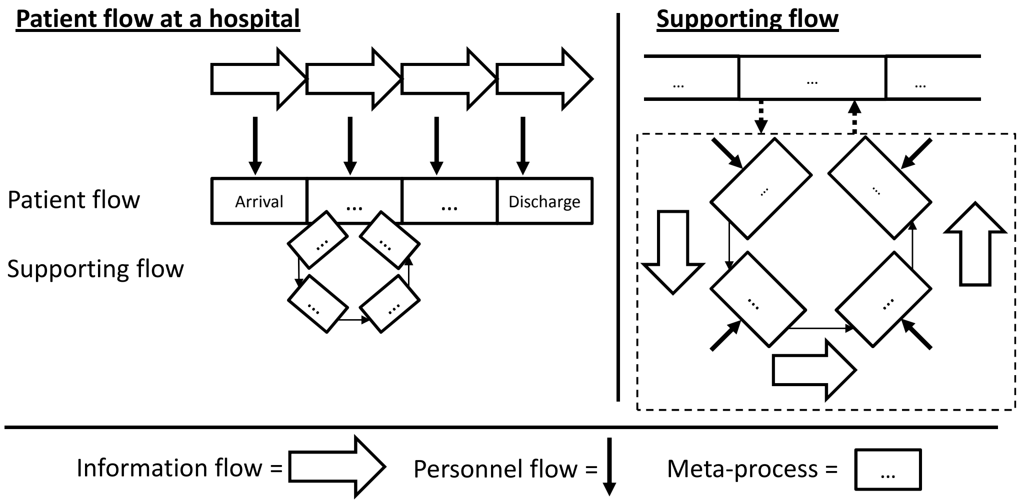


Figure 3: Patient flow and initiated flows at a hospital

A logistical system can be divided into a number of well-defined and delimited phases or meta-processes (for example, diagnosing a patient). Diagnosing a patient is not just one process but a sequence of processes (for example, testing the patient, interpreting the result etc.). Therefore, a meta-process can be further divided into a number of processes. These processes can be grouped within the meta-processes as either a pre-process, the process itself or a finishing/end-process. The meta-processes ensure that the logistical system is represented in a holistic manner.

The focus of this study is the supporting flows. The supporting flows are initialized by the patient flow and are very important due to their impact on the patient flow. Figure 4 shows two examples of a supporting flow.

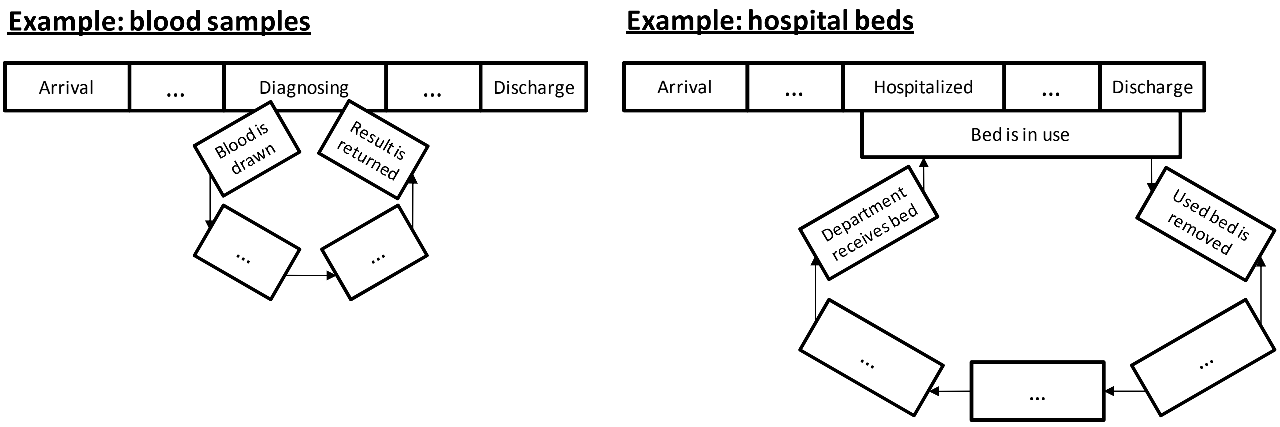


Figure 4: Examples of supporting flows at a hospital

In the blood sample case, the patient flow cannot continue before the supporting flow is finished, whereas in the hospital beds example, the supporting flow is initialized by the patient flow, but the two flows are executed independently. In both cases, the supporting flows are essential in order to secure an optimal patient flow and make the hospital function in the best possible manner.

1.4 Key concepts in the research

As presented in this chapter, the aim of the research is to construct a tool capable of analysing the logistical systems in a holistic manner with the aim of implementing new technology in a systematic approach in order to improve efficiency. This creates three issues that need clarification. First of all, what is meant by *improving efficiency*? Secondly, what is considered *holistic*? And lastly, how is a *systematic approach achieved*?

Improving efficiency relates to the term *effect* in figure 2. Effect can be related to many different issues, but overall, it is related to two issues: 1) decreasing the throughput time of the logistical system and 2) improving the quality of the logistical system. The aim to change the logistical system will therefore be driven by a desire to fulfil these two effects. The second issue is related to the analysis being *holistic*. As stated at the beginning of the chapter, there is a tendency to sub-optimize logistical systems in health care settings, because focus is concentrated on the departments. Securing a holistic approach therefore means that the entire logistical system needs to be considered, especially the processes involving interfaces between departments. These interfaces are especially important, because many bottlenecks occur in relation to interfaces, and the interfaces have a significant impact on material handling at hospitals. Finally, a *systematic approach* should be taken. The term systematic relates to two different things: first, identifying where implementation of technology will have the biggest impact in improving the overall system (securing a holistic view); second, ensuring that the correct technology is chosen. In relation to the material handling processes, it is important to identify how the transportation involved in the process is conducted. For example, is it between two points and thereby optimal for a conveyor system? Or is the transportation conducted over a large area, requiring some type of trucks or automated guided vehicles?

Although the theoretical foundation of the research comprises logistics, technology, structure and procedure, this research focuses only on changes within technology and logistics. However, the research also considers the influence changes have on both structure and procedure.

1.5 Summary

This introductory chapter presents the foundation for initiating the research. The challenges experienced in health care are initially presented. The overall challenge is an increased focus on lowering expenditures in health care due to demographic developments in the developed countries and as a consequence of the financial crisis. One of the major expenditures is related to the supply chain and the logistics within health care institutions. Also, logistics have been approached to a great extent using a departmental view, which leads to logistics being sub-optimized. A major Danish hospital, Herlev Hospital, has experience with these issues and is currently focusing on how to improve logistics, and how to use technology as the driver in this process.

Based on the need to address these issues, a literature survey was conducted within the areas of technology and logistics in health care. The investigation shows that both areas have been addressed and heavily researched. However, there is a lack in combining the two areas – in using technology to improve logistics. In addition to this investigation, the concept of material handling in industry is investigated. Two main areas of material handling are presented: 1) the use of an automation scale; and 2) the three categories into which the ways technologies can be used in material handling. Finally, the theoretical foundation of the research is presented, which combines the findings in the literature and the ideas originating from Herlev Hospital.

The logistical systems at hospitals are then presented with the aim of introducing the focus of the research. The main flow at a hospital is the patient flow, and in order to make the patient flow function optimally, there are information- and personnel flows as well as supporting flows that ensure that items are delivered when needed, for example, the equipment used in treatment, medication, food, linens etc. The supporting flow is the focus of this research.

Finally, some of the core concepts in the research are presented. They are related to the aim of the research. The first concept is improvement of a logistical system and what is meant by this. Improvement of the logistical system can either comprise a reduction in lead time or improvement in the quality of the system. The second concept is the holistic view of the system. Focus is on securing a holistic view of the system in order to avoid that the system is sub-optimized. The third concept is the systematic approach, which refers to two different aspects: first, the analysis should be conducted in a systematic manner that ensures identification of the part of the system with the greatest improvement potential; and second, that the correct technology is chosen.

Chapter 2 – Research Design

In this chapter, the scientific approach used in the research is presented and explained. To gain a comprehensive understanding of the research design and the scientific approach, the chapter is divided into five sections. First, the research problem is presented. This is followed by an introduction to the stakeholders in order to frame the research in terms of their interests and how the research can help explore their interests. The third section presents the research questions driving the research. These questions are related to the research problem, and they guide the different phases of the research. The fourth section presents the methodological approach used in order to answer the research questions and solve the research problem. As part of this, the limitations posted by the methodological constraints are considered. The final section presents the expected outcome of the research.

2.1 Research problem

The empirical and theoretical considerations presented in Chapter 1 comprise three major issues: the constant pressure hospitals face to deliver more efficient health care; the lacking exploitation of technologies within health care logistics; and the on-going development of new technologies. These issues have led to the research problem and the meta-question that this research addresses:

> *How can technology be used within health care logistics to make it more efficient, and how can the potential of the technology be determined in a systematic and transparent manner?*

The thesis addresses this question by constructing an analytical framework capable of analysing the current logistical system and assessing its performance. Furthermore, the analytical framework can be used to determine the potential of implementing different technologies. The research follows two tracks in the pursuit of such a framework. The main track focuses on the development of the framework, and the supplementary track uses simulation as the approach to validate the results from the framework.

2.2 Stakeholders

This research has two main stakeholders, the scientific community and hospital managers. Ultimately, patients and the government will also benefit from the research. Industry also has an interest, since it produces the technological solutions. Each stakeholder has different interests, which are overlapping to some extent but can also be contradictory. Due to the nature of this project and the motivational ground for conducting the research, it is of great importance to take the stakeholders' interests into account and try to address them in the best possible way.

The outcome of this research is a tool that hospital management can use on the strategic and tactical levels in order to make the operational level function more efficiently. The interest of the different stakeholders in this project relates therefore to these three levels and can be mapped accordingly (see figure 5).

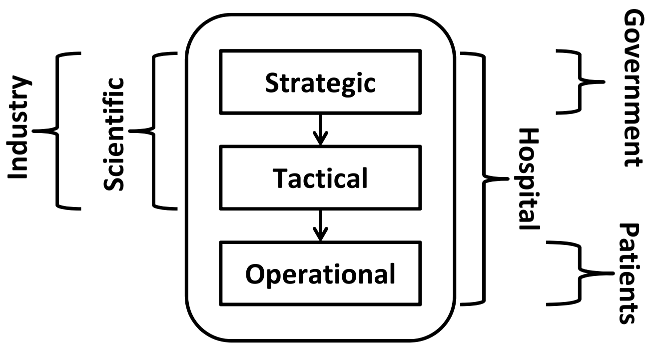


Figure 5: The stakeholders' level of interest

Scientific community

The scientific community's interest is to bring new scientific knowledge into the already existing literature. It is interested in the theoretical contribution presented in this study, published in journals and presented at conferences, as well as the empirical results. The theoretical and practical results give a better understanding of what is important to consider when working with technology in logistical health care systems. The results fill some of the gap between the work on logistics in health care and technology in health care. The publication strategy has been to publish the ideas as they are developed, from the conceptual level to the practical level. The practical level consists of cases where the proposed technologies have actually been implemented or where implementation projects have been initiated.

The research has been presented to the scientific community through six scientific papers, three conference articles and three journal articles. Especially the presentation of the scientific work in the conference papers has helped the further development of the theoretical results. Discussing the results and adjusting them in collaboration with fellow researchers at conferences have further validated the outcome of the research, and publicising the research results in scientific journals has further enhanced the validation of the research outcome. The research has been published in connection with three different conferences and in three different journals, which indicates that there is broad interest in the topic.

The main interest in this research is related to the scientific community within management on the strategic and tactical levels; however, the research has been presented not only to different types of management communities, but also to medical communities, for example, one journal article was written in collaboration with an executive medical consultant at Hvidovre Hospital.

Hospitals and hospital management

The importance of the hospitals and hospital management in terms of outcome of the project cannot be overstated. If the results from the research do not live up to the standards set by the involved hospitals or do not take into consideration their perceptions of what, according to their experience, is most important, then the research will have no practical impact. It is possible to identify gaps in research, but it is extremely important that a practical need exists to fill this gap. Otherwise, the research may be perceived as trivial to practitioners. At the same time, the basis for this research is the lack of a tool for solving the practical problems experienced by hospital management.

Hospitals and hospital management are under tremendous pressure to make the hospitals function more efficiently. There is therefore an emerging need to exploit all aspects of the possibilities to make hospitals more efficient. The aim of this research, to develop an approach where technology can be used as the driver to develop more efficient logistics, is therefore perfectly in line with the challenge facing the hospitals. In the execution of this project, close collaboration with Herlev Hospital has been maintained, and the logistical system at the hospital has been analysed. The results of the analysis have been used as empirical material in the evaluation process of whether or not to adapt the technological solutions presented in the model. The research results have led to technological implementations as well as further economic investigation into other proposed technologies.

Although the hospital has a lot of focus on making more efficient logistics, the main interest is to secure high quality patient treatment. This aspect has been considered and incorporated in the development of the research.

The research outcome is therefore used on strategic and tactical levels in the pursuit of more efficient logistics, and the solutions are implemented on an operational level.

Patients

The logistical systems considered in this research do not involve patients, but the flows of interest are highly dependent on the patient flow and initiated by the patient flow. Due to the iterative interaction between the patient flow and the different supporting logistical flows, patients have an interest in the supporting flows delivering the right items in the correct quantities at the right time. Therefore, it is very important for the patients that the technological solutions ensure that the items involved in the logistical system are transported and handled with focus on safety and securing a high quality patient treatment. This is ultimately in line with the hospitals' interests. In order to take these concerns into consideration, quality issues have been included in the analysis of the current situation, as well as in the evaluation of possible technological solutions.

The patients' interests are therefore on the operational level, and in the effect of the implementations on daily treatment.

Government

Since the Danish health care system is almost entirely publicly funded and the Danish hospitals are under the auspices of the Ministry of Health, the government ultimately also has a stake in the project. The stake is similar to that of the hospitals, but perhaps with even greater focus on patient safety (no scandals) and more efficient logistics (balancing the national budget). Ultimately, the government interest is to obtain more efficient logistics that creates fewer errors. As a result, government interest is primarily related to the strategic level, since the government, as the hospital owner, has a major say in strategy.

Industry

The industry interests are related to the technological solutions. Since the technological solutions presented and analysed are delivered by various companies, the research has an advertising function in relation to the companies. At the same time, in order to make a comprehensive analysis, the research is dependent on obtaining knowledge about the technological solutions. As a consequence, it is extremely important to be aware of this link and make sure that both positive and negative aspects of the different technological solutions are considered and included in the analysis. Since industry's main interest is for technology to be implemented, their main interest is at the strategic and tactical levels.

2.3 Research question

In the pursuit of addressing the research problem and making sure that all aspects of the research problem are covered, the research question acts as a strict guideline. The research question consists of one meta-question (MQ), which grasps the essence of the research problem, and three sub-questions (SQ), which ensure that the research problem and overall research question are addressed comprehensively.

The SQs were developed so that the project took its starting point (SQ1) in the theoretical issues concerning what needs to be considered when dealing with logistical systems and technology in health care. The project then focused on developing a practical framework capable of analysing logistical systems and assessing the potential of implementing technology (SQ2). Finally, the project ended by taking the framework to the real world and focusing on specific cases and how existing systems can be enhanced by using the developed framework (SQ3).

Of the articles written and published throughout the project, four address the SQs and two deals with simulation and how to assess the potential of a technology by using simulation.

Sub-question 1 – theoretical foundation for research

The initial stage of the research was to layout the theoretical foundation. The theoretical foundation was primarily based on the experience of hospital managers. In the literature, much investigation has been made into how to make more efficient logistics using LEAN as one of the main drivers. The focus is on how different technologies can help improve single processes, but there has not been much focus on how technology can be used as the main tool in the attempt to make logistics more efficient.

> *What are considered the most important aspects when dealing with technological implementations in health care logistics?*

In order to address this, it was important to make a thorough inquiry into the literature concerning logistics in health care, as well as what health care managers perceive to be most important. In the process of investigating and answering SQ1, the conceptual model for the project was defined. It consists of the four elements: logistics, technology, structure and procedure.

Sub-question 2 – construction of a framework

The next part of the project was to transform the findings from SQ1 into a framework capable of analysing the logistical systems. In the process of doing this, two different issues needed to be considered. A guideline needed to be constructed for how to do the analysis, and also how to assess the logistical system in order to gain insight into the current system as well as determine the potential of making technological changes. Concurrently, it was important to have a holistic overview of the entire logistical system in order to ensure avoiding under-optimization.

> *How can a framework be constructed that contains the relations between logistics, technology, structure and procedure and still maintains a holistic overview of the system?*

In the quest to address this SQ, a couple of issues needed to be considered. The approach to assess the systems needed to be considered, since this is the basis for determining the potential of implementing technology. In the process of constructing such an assessment tool, it is important to incorporate the four elements in a comprehensive manner, ensuring that the considerations of the health care managers are fully addressed. The assessment tool thereby functions as the approach to gaining insight into the system. It is therefore important to construct structured guidelines that ensure a holistic view of the system. It is also important to be aware that whenever one of the elements is changed, it has an impact on the overall effect.

Sub-question 3 – making the framework into a reliable and applicable tool

The final part of the project dealt with creating an applicable and reliable tool that can produce results that can be used by hospital management in strategic decisions regarding whether or not to make changes. In this work, it was important to understand and consider the implications in using such a framework in practice. It was also important to ensure that the analysis obtained from the framework was reliable and in accordance with real life. SQ3 dealt with these issues.

> *What are the implications of using such a framework in practice and implementing the technologies?*

To ensure that the framework provides a reliable analysis, it was important to test the framework on real- life cases. In this process, it was very important to investigate the aspects hospital managers consider the most important when using such a framework. Applying the framework to specific cases ends with some recommendations in terms of the potential of different technologies. Based on these recommendations, hospital management can then decide whether or not to move forward with the implementation.

Simulation

A simulation project was initiated concurrently with the development of the framework. Simulation is a very powerful tool in terms of determining the operational impact of changes. The framework developed in this project is primarily a tool to be used at the strategic and tactical levels, but also in relation to impact on the operational level. The simulation tool in this regard can help in terms of validating whether the expected operational changes are in accordance with the simulation project's findings. This is done by simulating similar logistical systems and checking whether the results are in accordance.

Although simulation is a very powerful tool for testing the potential of different technologies, there are some issues involved in using simulation instead of the framework developed in this project. Constructing comprehensive simulation models of logistical systems is a very time and resource consuming process in comparison with the framework. This makes simulation less suitable in a situation where a quick overview of different technologies and their potentials is needed for multiple logistical systems. When using simulations, the primary focus is on the effect changes have on operational performance, for example throughput time. One of the aims of the current project was to identify what has the greatest importance when dealing with technological changes in logistics. Four different elements were defined, but including these elements in a simulation model, as well as the links between them, was not possible to the same extent as was the case with the framework. The analytical framework is thus the tool used to generate solutions, whereas simulation tests the operational performance of the solutions.

2.4 Research methodology

The outcomes from the three sub-questions depend to a great extent on what philosophical standpoint the research is based on as well as the methodology used to gather the empirical data on which the answers to the research questions are based. It is therefore very important to determine the research's philosophical standpoint and investigate its implications and consequences. It is also extremely important to have a clear view of the implications and requirements of the chosen methodology. This section addresses some of these concerns. As the philosophical standpoint for this research is critical realism, a short introduction to critical realism is presented together with some concerns regarding this particular project.

The main approach in this research is case research, which is described below together with how the issues related to case research have been incorporated in the study. Finally, a short description is given of how the literature survey was conducted.

Philosophy of science

In conducting research, there are many aspects that need to be considered in order to be able to evaluate the results obtained. Some of these concerns are related to the assumptions made, the foundation of the research, the method used in conducting the research and how the results have been interpreted and presented. Philosophy of science deals with how research is perceived and the issues related to this perception, such as ontology and epistemology. Bertrand Russell states in his book, *A History of Western Philosophy* (1945), that philosophy is something in between theology at one end and science at the other; meaning that all definite knowledge belongs to science, and all dogma that surpasses definite knowledge belongs to theology. Between these two extremes is a gap, which he denotes as No Man's Land. It is this space that defines what philosophy is. All questions that science cannot answer and that theology seems too speculative to answer are located within the area of philosophy. In this light, the role of philosophy of science is to figure out which answers science can provide and how this is to be done. Therefore, it is very important to be aware of which philosophical standpoint is in line with the methodology used in the research in order to clarify how the data is to be gathered and analysed. In this research, the philosophical standpoint is critical realism.

Another issue in relation to philosophy of science is the context in which the research has been conducted, and which boundaries this context places on the research. The research is conducted within a health care setting, and the health care professionals have some predetermined notions of what is perceived as usable research. The scope of the research is to improve hospital logistics, and due to the overall challenges that health care is facing, improvement is related to making processes function economically better with high clinical quality. If the research does not address this, the research will not be considered feasible for the users of the research (the stakeholders).

Critical realism

Critical realism is a post-positivism paradigm that tries to deal with some of the ontological and epistemological flaws of positivism. It was largely established by the writings by Bhaskar (1975 and 1997). Critical realism is often perceived as a type of middle ground between empiricism and positivism on the one side, and anti-naturalism on the other. Critical realism thus tries to propose a new form of realist ontology. One of the main characteristics of critical realism is the strong emphasis on ontology. This is also in accordance with the eight key assumptions postulated by Sayer (1992). Therefore, critical realism perceives that the world exists independently of what we might think of it. Thereby, we realise the imperfection of knowledge and the possibility of getting things wrong. Bhaskar (1998) argues that there are two different types of knowledge and differentiates between transitive and intransitive objects of knowledge. Intransitive objects of knowledge do not depend on human activities; that is activities that are not invented by humans – for example, physical laws such as gravity. Transitive objects of knowledge are on the other hand a product of the scientific knowledge available at the time. Examples of this type of objects are established facts, paradigms, theories, models, methods and techniques used to conduct research. Another point made by Bhaskar is that one of the key ontological assumptions of critical realism is that the world is a stratified open system (1975 and 1997). This means that unobservable events produce changes at the observable level. This is related to this research in that the logistical systems that are analysed are influenced by outside impact.

One of the practical implications of choosing the critical realist philosophical standpoint relates to how to conduct research. It is crucial that the researcher is critical in evaluating the object being studied in the effort to gain understanding. In practice, this means that a continuing and very thorough validation of the models developed needs to be conducted. The perception of the world as a stratified open system has great impact on how the results of the research are to be interpreted. The setting within which the research is conducted is never completely closed, and changes happening on an unobservable level may have impact that cannot be directly explained. It is therefore important to be aware of the context in which the research is being conducted and the impact this has on the outcome. This is especially important in relation to validating the results in other settings and using results developed in other settings.

Critical realism in this study

In this research, the aim is to gain insight into what are perceived to be the most important issues regarding implementation of technology in logistical systems within hospitals. The main collaborator is Herlev Hospital, and the main part of the research was conducted in this hospital setting. Other hospitals have been involved as well, but the level of involvement has been on a lower level. Therefore, the research methodology used is case study research. The combination of case study and critical realism is a good one according to Geoff Easton (2010):

> Critical realism is particularly well suited as a companion to case research. It justifies the study of any situation, regardless of the numbers of research units involved, but only if the process involves in- depth research with the objective of understanding why things are as they are.

Sayer (2000) explains how a critical realist identifies the view of causation, which is pertinent to the goal of this study: to determine the relation between the four elements and their effect on performance (see figure 6).

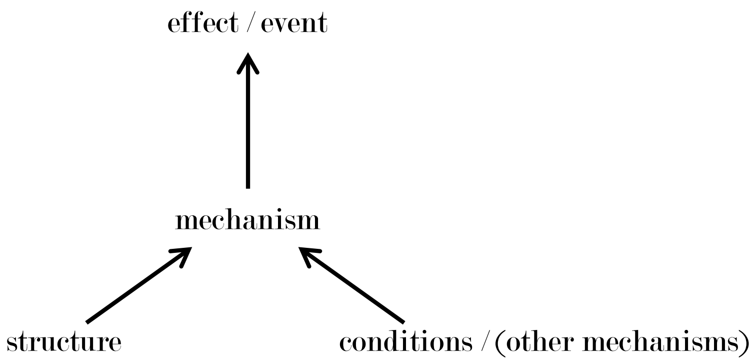


Figure 6: Critical realist view of causation (Sayer 2000)

A main issue in relation to conducting research using critical realism as the philosophical standpoint is the need to carefully validate the findings by testing the results in different settings. Eaton introduces the concept of "retroduction" (2010, p. 124), which is concerned with what causes particular events to happen. It is usually an iterative process. In the present research, this has been dealt with by conducting the research in multiple cases and carrying out a simulation project to further validate the results. It is important however that the cases' foundations are similar, so that the results from the cases are comparable and the outcome valid.

Case study research

The main methodology used in this research was case study research. Voss (Karlsson 2009, p. 164) uses the following definition of case study:

> A case study research is a history of a past or current phenomenon, drawn from multiple sources of evidence. It can include data from direct observation and systematic interviewing as well as from public and private archives. In fact, any fact relevant to the stream of events describing the phenomenon is a potential datum in a case study.

Using case study as the research methodology has three main advantages, also presented by Voss (Karlsson 2009, p. 164):

- The phenomenon can be studied in its natural setting and meaningful, relevant theory can be generated from the understanding gained through observing actual practice.
- The case method allows the questions of *why*, *what* and *how,* to be answered with a relatively full understanding of the nature and the complexity of the complete phenomenon.
- The case method lends itself to early, exploratory investigations where the variables are still unknown and the phenomenon not at all understood.

In the current research, the aim was initially to gain insight into the link between technology and logistics in health care. Following the initial investigation, the aim became to develop a model and test it. Case study was in this situation an excellent approach. It can act as a powerful tool in determining how the model should be constructed, as well as what functions optimally and what should be changed.

A major issue with regard to case studies is the selection of cases. In this type of study, it is very important that the boundaries for the study are directly connected to the research question (Voss et al. 2002). It is also very important to choose cases that that can fully uncover, confirm or qualify the basic processes or constructs that underpin the study. In this study, this has been addressed by having a very specific definition of the type of logistical systems that should form the basis for this research; then, cases that fit this definition were chosen.

The research included eight different cases from four hospitals – two Danish and two Japanese – with different levels of involvement that varied from being involved in testing, modifying and verifying the model, to receiving a full analysis of a specific case with recommendations for changes.

Cases	Size of hospital (beds)	Country/ Involvement
Hospital A	**1200 – 1300**	**Denmark**
- Transportation of acute blood samples - Bed logistics - Logistics of surgery tools		- Analysis of cases - Recommendations presented to hospital - Recommendations implemented
Hospital B	**1000 – 1100**	**Denmark**
- Transportation of planned blood samples		- Analysis of cases - Recommendations presented to hospital - Recommendations implemented
Hospital C	**400 – 500**	**Japan**
- Logistics of surgery tools - Transportation of planned blood samples		- Testing the model
Hospital D	**500 – 600**	**Japan**
- Transportation of acute blood samples - Bed logistics		- Testing the model

Table 1: Cases involved in the development and testing of the model

In order to conduct the case studies, two different data collection methods were used – observations and interviews.

Observations

Observations are extremely important in order to gain thorough insight into how the organisation being analysed is constructed and functions (Maaloe 2002). In this research, on-site observations were used to a large extent. The on-site observations had different purposes, depending on which part of the research the observations were involved in – developing the model or testing and validating the model.

In the initial process of the research, where focus was on creating the framework, on-site observations were used to gain insight into how logistical systems at hospitals are constructed, and what issues are related to the logistical systems. First of all, observations served as a good tool for gathering knowledge about how hospitals are constructed and the logistical systems found at the hospitals. Observations also gave a good understanding of what is important concerning these types of logistical systems and what particular quality requirements are particularly important. In addition, the initial observations gave an understanding of the interactions between different departments at hospitals as well as the interactions between logistical systems and the patient flow.

In the later part of the research, the on-site observations were used in the testing of particular logistical systems. In this part of the research, all the processes were mapped, and the specific logistical systems described in detail, including all the processes performed, the personnel groups that performed them, where the processes were performed and in what sequence. In accordance with the focus of this research, the observations also helped to determine to what extent technology was used in the execution of the logistical system.

Conducting observations also pose a concern. Is full insight into the system gained? It is very important to have a thorough research protocol to guide the research in order to ensure that all necessary information is recorded. Missing out on specific details can have severe consequences for the research results. It is also very important for the researcher to make objective observations. It is therefore necessary to have an open mind when conducting the observations, since they can be biased if the researcher has a predetermined stance regarding the object of study.

Interviews

Interviews were also an extremely important part of the research. Interviews are a very good tool for gathering knowledge from experts in the field of research. As in relation to observations, it is extremely important to have a very good and thorough guideline for the interviews. Yin (1994) lists five skills that necessary:

- To be able to ask good questions and interpret the answers.
- To be a good listener and not be trapped by preconceptions.
- To be adaptable and flexible, to see newly encountered situations as opportunities not threats.
- To have a firm grasp of the issues being studied.
- To be unbiased by preconceived notions, and thus receptive and sensitive to contradictory evidence.

There are many different approaches to constructing interviews. They can be unstructured, focused with more structure, or highly structured like a questionnaire. The approach used in this research has been semi-structured interviews. A thorough interview guide was constructed with questions grouped within different topics. The interviews had a strict aim regarding what information should be retrieved. When the interviews were conducted, however, it was very important for the researchers to give the interviewees the opportunity to tell their own story while the researcher just guided them to stay within the predetermined areas of focus. Interviews were also conducted both in the initial phase of the research (construction of the model) and in the later phases (testing, modification and verification of the model). In the initial phase, only one hospital was involved, and the focus of the interviews was to gather knowledge to build the foundation of the research and the analytical framework. This was done by interviews with top management, administrative personnel and clinical personnel. For all the interviews the focus was on what is perceived as the most important issues when dealing with technology within logistical settings at hospitals. In addition, the aim was to determine what quality issues should be considered concerning health care logistics.

In the later phases of the research, all four hospitals and all eight cases were involved. At each of the hospitals, interview sessions were conducted with three different employee groups: top management, administrative personnel with responsibility for logistics, and clinical personnel. On the overall level, the focus of the interviews was two-fold: (1) gaining insight into how the particular logistical system was structured for the particular hospital, (2) understanding how the model would fit with the specific logistical system at the specific hospital.

The interviews with top management were used to gain insight into their hospital, the most important factors in relation to their hospital, the perception of logistics in their hospital, and the role new technology plays at their hospital. One person from top management from each of the hospitals was interviewed.

The interviews with the administrative personnel focused on how they measure the logistical performance, and what was most important in terms of controlling and monitoring the logistical systems. Two persons from each of the Japanese hospitals and three from each of the Danish hospitals were interviewed.

The interviews with the clinical personnel focused on the practical implications on a day-to-day basis. During the interviews the concepts of the framework were presented and discussed. In addition, it was studied whether the model was adequate for assessing the possibility of implementing new technology in logistics.

As with observations, it is extremely important that the interviews are conducted in the correct manner in order to ensure that valid information is obtained. It is therefore very important to make sure that the position of the interviewee is considered when analysing the answers. In one of the cases in this research, some of the clinical personnel advocated strongly against a technological solution at an early state in the interviews. Later on, however, they were very positive towards the same technology. In this particular case, it was very important to be aware of why they answered as they did in the beginning, and why the perception changed at a later stage.

Literature study

In the initial phase of the research, a thorough literature survey (Karlsson 2009) was conducted in order to gain insight into the research area by combining "hospital" and "health care" with "logistics", "supply chain", "technology", "robot", "automatic" and "automation". The search was conducted in PubMed and the DTU database, which contain more than 159 million article references from publishers and leading 'scitech' abstract databases. The findings from the literature survey were then combined with the initial interviews in order to construct the conceptual foundation for the research.

Simulation

Concurrent with development of the model, a simulation project was conducted. Simulation imitates the operations of a real-world process or system over time (Banks & Spearman 1997), and can be used in relation to different operations within industry, service and health care (Karlsson 2009). Computer simulation is a tool that allows the model maker to construct a model that imitates an actual system, making it possible to conduct experiments and estimate the effect of changes to the actual system (Pidd 2009).

Using simulation gives a number of benefits. It is possible to construct experiments without actually making changes in the system; thereby, it is possible to estimate the consequences of making the changes. Simulation can also be done much faster than real-life experiments, thus providing the opportunity to test many different alternatives rather than just one alternative at a time.

In this study, discrete-event computer simulation was used. Discrete-event systems allow one or more phenomena of interest to change value or state at discrete points in time rather than continuously along the time line (Fishman 2001). The simulation tool used in this study is MedModel®. MedModel® is constructed specifically for simulation within the health care sector.

Simulation was chosen due to its usefulness in the validation process of this research. It is a very good communication tool due to the visual interface, thereby it is possible to present the model to the collaborators and get a verification of the model, even though they are not experts on the mathematics used to construct the model. The simulation could therefore be used to validate and verified the analytical framework.

2.5 Limitations

When the decision is being made about what approach to use to explore the research questions, it is very important to be aware of the implications these choices have on the outcome of the research. It is also important to be aware of the implications in relation to the analysis of the results.

Scientific boundaries

When designing and conducting research, it is important to be aware of the boundaries within which the research is performed. In this project, three major areas were identified as the most important in determining the scientific boundaries: the temporal, theoretical and empirical boundaries.

Probably the most obvious constraint is the time frame of the PhD. In Denmark, a PhD has a time frame of three years, which sets a limit for how much time can be used for each phase of the project. A PhD student must work according to a strict plan for the project in order to ensure that all deadlines are met and the project is finished on time.

The foundation of the research is based on theoretical and empirical concerns. The theoretical basis for this research is the literature within logistics and use of technology in health care. As discussed in Chapter 1, there is a lack of literature dealing with these specific areas and therefore the theoretical boundaries for the project are quite broad. The empirical boundaries, however, have had a strong effect. While Hvidovre Hospital, which is also a major Danish hospital, and two Japanese hospitals were involved in the research, they had fewer stakes in the project than Herlev Hospital, which were involved in a close collaboration, especially in the initial part of the project when the model was developed. Therefore, Herlev Hospital had a great impact on the foundation of the project, and the issues identified by the hospital had a great impact on the construction of the framework and the model. Examples of Herlev Hospital's influence are the two elements (structure and procedure), which were presented by the hospital. If another hospital had been involved in this phase of the project, the conceptual model might have been different.

Validity

An extremely important issue to consider when conducting research is the validity of the research results. Validity is understood as the strength of the research's conclusions, inferences or propositions. Cook and Campbell (1979) define validity as the "best available approximation to the truth or falsity of a given inference, proposition or conclusion". To determine validity it is therefore necessary to check whether the results are correct. In natural science, this is done by conducting the same experiment over and over again using the same laboratory settings. In a research project like this one, however, it is difficult to obtain exactly the same results, since it is not possible to construct closed laboratory settings. It is therefore difficult to determine whether the results are obtained from the research or whether some outside influence has actually caused the changes.

The methodology tries to deal with some of these issues by continuously conducting tests and validation processes. Furthermore, different settings were used in order to ensure that the results are valid for more than just one particular setting. This is especially important when constructing a model that should be applicable in many different settings.

Another issue in relation to validity is similar to the concern expressed in the section on interviews. Trochim and Donnelly (2006) describe three different types of social threats to the construct of validity:

- Hypothesis guessing: When participants base their behaviour on what they think your study is about – so your outcome is really not due solely to the program – but also participants' reaction to you and your study.
- Evaluator apprehension: When participants are fearful of your study to the point that it influences the treatment effect you detect.
- Experimental expectancies: When researcher reactions shape the participants' responses – so you mislabel the treatment effect you see as due to the program when it is more likely due to the researcher's behaviour.

The approach used to address these issues is explained in the interview section, and will also be dealt with in Chapter 5 – Discussion.

Generalising potential

Constructing a model based on case research always poses the issue of how applicable the model is in other settings than the one in which the model was developed. In this research, there were two different concerns related to the generalising potential; Is the model a Danish model? And on what types of logistical systems can the framework be applied?

The framework's main development and modification occurred in a Danish context. The Danish cases were much more involved in the creation and modification process of the research. The Danish cases have also used the results obtained from the analysis in the process of making their logistical systems more efficient. However, the framework was tested on four cases from two different Japanese hospitals in order to test the framework's applicability in very different settings. The output from this process has been considered and implemented in the framework. The logistical systems used in the Danish and Japanese cases are similar in order to ensure that only one parameter has been changed at a time.

The framework developed in this research has been developed and tested on a specific type of logistical system, the supporting flows. It is possible that the model would also have merit within other logistical settings, but this has not been tested in this project and is outside the scope of the research. A further discussion of this is to be found in Chapter 5 – Discussion.

Practical limitations

The research presented in this project was very focused on practical problems and how these practical problems can be solved. The approach was to construct a theoretical model to address the problems and ultimately solve them. This posed two major obstacles that needed to be considered: 1) How to ensure that the model can be understood and used by the hospital managers in their efforts to make hospitals more efficient? 2) How to ensure that the organisation implementing the analytical framework's recommendations embraces the changes?

The first issue is related to an old saying by the Danish-Norwegian writer Ludvig Holberg (1723): "It is one thing to understand a nautical chart; another is to steer the ship." It is of utmost importance that hospital management is closely involved throughout the entire research so that their concerns are incorporated in the development phase. This also ensures that they gain insight into the framework's construction and that the framework can be modified to fit their working routines.

The second issue is well described in the literature and concerns resistance to change (Kotter 1996). Applying the framework to a specific case should ultimately lead to implementation of a technology. The implemented technology will have great impact on the working routines and procedures of the personnel affected by the change. The risk therefore exists that the personnel will be very resistant towards the implementation. The research tries to address this problem by revealing the impact of the technology at the structural and procedural levels and thereby make known the positive impact the technology will have on the personnel's daily working routines and procedures.

2.6 Expected outcome

Based upon the research problem, the research questions, the methodology and the stakeholders presented in this chapter, the expected outcome of the research can be estimated. The research had two different outcomes, primary and secondary. The primary outcome was related to the direct aim of the research; the secondary outcome was not directly related to the aim but uses the results from the research in a slightly different manner.

Primary outcome

The primary aim of the research was to identify the most important issues when dealing with technology in health care logistical settings and develop a framework that addresses these issues. In this light, the primary outcome was the understanding gained regarding the most important issues and the construction of an applicable framework to be used to improve the current logistics. This project has hopefully produced some theoretical insights that can be used in future research concerning technology in hospitals' logistical settings.

It was also expected that use of the framework could result in recommendations to be presented to the involved case hospitals on how to improve the logistical cases involved in the research. In this light, it was hoped that actual changes could be implemented during the project. Due to Herlev Hospital's extensive involvement, it is hoped that actual efficiency benefits will result from the implementations made based on the analysis.

Secondary outcome

The risk often exists that results obtained from a research project like this will only be used by the researcher and then be archived later on and forgotten, or used merely in a theoretical context. Due to the close collaboration with especially Herlev Hospital, it is hoped that the research's results and findings can be incorporated in the hospital's future approach to constructing logistical systems and making changes in current systems. In this way, the theoretical results will be transformed to a practical tool that the hospital management can use in the future.

2.7 Summary

The primary aim of the research is to construct a framework capable of analysing logistical systems and propose technological changes that will help improve these systems. The research problem is introduced at the start of the chapter, followed by an introduction of the project's five different stakeholders divided into primary (scientific community, hospitals and hospital management) and secondary stakeholders (patients, government and industry). Each of the groups is described, together with their particular interest in the research. The next section presents the research question formulated to fulfil the research problem. The three sub-questions each answer different parts of the overall research question. Sub-question 1 deals with the theoretical foundation for the framework. Sub-question 2 focuses on how the framework should be constructed. Sub-question 3 addresses how to transform the framework into a reliable applicable tool and the use of the framework in real cases.

Following the research questions, the philosophical standpoint and methodologies are presented. The philosophical standpoint is critical realism, and some comments are made regarding the implications this has for the research. The methodologies used are case study research and simulation, and each of these is presented along with concerns about what to be aware of and the way they have been used in this research.

The next section introduces the reader to some of the scientific limitations considered in the project. Finally, the expected outcome of the research is presented. This is divided into primary outcome, focusing on the direct use of the research, and secondary outcome, focusing on the derived use.

Chapter 3 – Empirical Foundation

This chapter presents the empirical material used in the research. The research presented in this study is based on case studies. It is therefore of utmost importance to have a clear picture of the different cases used in the research. The cases have been divided into primary and secondary collaborators corresponding to their level of involvement. In addition to the cases, the type of data gathered during the research is presented.

3.1 Primary collaboration

Herlev Hospital is one of four major hospitals in the capital region of Denmark, and one of the country's biggest hospitals. Herlev Hospital has more than 4,500 employees and 22 departments covering almost all diseases, and it uses the most advanced technology for treatments. The hospital has more than 1,500 beds and covers a population of 425,000 inhabitants with a 24-hour emergency department.

Herlev Hospital was chosen by the government as one of the future super hospitals in Denmark, which resulted in an expansion of 50,000 m2, with an estimated construction value of more than € 300 million. A whole new building will be constructed as part of the expansion, which will present many logistical challenges as a result. The research has been planned and carried out in close collaboration with the hospital's department for Internal Service and Logistics (ISL). This department is responsible for a number of different departments involved in either logistical or service tasks at the hospital. Among the functions for which ISL is responsible are the central kitchen (delivering food to all patients), sterilization central (for all used surgery utensils), supply and transportation services and others. The department has the operational responsibility for these different functions as well as the responsibility for developing the functions in order to cope with future challenges. In addition, the department is deeply involved in the decisions on how to handle the logistic challenges emerging from the expansion of the current hospital.

It is the strategic goal of ISL to try to improve the current logistical systems by using technology. In this process, they have developed a model to guide the technological changes. In this model, the focus is to make sure that employees' training is in line with the technology and the changes in procedures and structures that the technology requires. The model is part of the empirical basis used in the development of the framework for this research and has acted as inspiration in constructing its foundation.

Three different cases from Herlev Hospital were involved in the research. In each case, the departments that interact in the logistical system were involved in analysing, mapping, identifying the quality aspects of the system, identifying technological possibilities, and assessing the outcome of the analysis. The three cases used are *Acute blood samples*, *Bed logistics* and *Surgery utensils*.

As explained in chapter 2, interviews and discussions were conducted with personnel from each of the involved departments in order to gain full insight into the impact of the logistical system in terms of the structure and working procedures in the department.

Acute blood samples involves the system for taking blood samples in the emergency department and transporting them to the laboratory for analysis. In the research, both the emergency department and the department for Clinical Biochemistry (responsible for the laboratory) were involved in analysing the case and gathering information. This case was also included in the simulation project.

Bed logistics involves hospital beds used by patients during their stay at the hospital. Patients can either be placed in a bed when they arrive in the emergency department (acute patients) or when they are admitted directly to one of the departments (elective patients). The emergency department, the sterilization central and the medical department were involved in the research. The emergency department was involved because 50% of the beds are used here. The sterilization central is responsible for washing the bed, and the medical department has hospitalized patients. So the department receives clean beds for elective patients and also has used beds that need to be picked up for sterilization.

Surgery utensils involves utensils from surgery that need to be sterilised after use in an autoclave. Both the sterilization central and the anaesthesia department were involved in the research. The sterilization central is responsible for sterilizing the utensils and packing utensils for future surgeries. The anaesthesia department is involved in all surgeries and is therefore involved in both receiving sterile utensils and having used utensils picked up.

The involvement of the hospital has had some practical outcomes. As a result of the analysis of the *Acute blood samples* case, the hospital implemented a pneumatic tube system. Concerning the *Bed logistics* case, the hospital is conducting investigations to find out how a system can be implemented that ensures that all beds at the hospitals are monitored. Additional investigations are being made with regard to using robots to transport beds around the hospital, as well as an automated washing system for the beds. As an overall result of involvement in the research, the hospital has decided to use the ideas presented in the research in its future approach to constructing logistical systems and changing current systems.

Herlev Hospital has also been involved in financing the project. Part of the research was funded by the hospital, and office space was placed at the researcher's disposal.

3.2 Secondary collaboration

Besides Herlev Hospital, another Danish hospital was involved in the research, as well as two Japanese hospitals.

Hvidovre Hospital

Hvidovre Hospital is also one of the main hospitals in the capital region of Denmark. It has approximately 2,900 employees and is one of the main maternity hospitals in Copenhagen. Hvidovre Hospital also plans to be expanded as a result of the Danish health care reform, and it is expected that the existing hospital will be expanded with more than 30,000 m2.

Hvidovre Hospital has been involved with one case, *Planned blood samples*. These blood samples are planned blood tests that are ordered by the bed wards, whereupon biomedical technicians go to the bed wards to draw the blood samples. The blood samples are then transported back to the laboratory where the analysis of the blood samples is conducted.

Hvidovre Hospital's involvement is related to two different parts of the research. The case was analysed using the analytical framework and was involved in the simulation project, and was therefore important in testing whether the results obtained from the simulation were similar to the results from the analytical framework, thereby enhancing the reliability of the analytical framework. As a result of its involvement, the hospital is currently in the final process of implementing a pneumatic tube system.

Japanese hospitals

As explained in the Chapter 2, two Japanese hospitals were involved in the research in order to test and validate the developed framework and ensure that the framework would not just be a Danish model but would also be applicable to other settings. The two hospitals are both located on the southern Japanese island of Kyushu.

Yahata General Hospital

Yahata General Hospital is located in the city of Kitakyushu and has a 24-hour emergency department. The hospital's focus is on emergency patients. Patients under more complicated, longer lasting treatment are transferred to a specialist hospital. The hospital has 403 beds and is one of many general hospitals in Kitakyushu.

The cases *Surgery utensils* and *Planned blood samples* were used at this hospital, which has six operating rooms. The sterilization process is performed next to the operating rooms. The cleaning, sterilization and packing of the surgery utensils were performed almost entirely manually. The logistics related to *Planned blood samples* were similar to the Danish case.

Kitakyushu Municipal Medical Centre

The hospital is located in the centre of the city Kitakyushu. It is a general hospital with 636 beds with approximately 50 beds in each bed ward.

The hospital participated in the research with the cases *Bed logistics* and *Acute blood samples*. The hospital differed from the Danish cases of *Bed logistics*, because the beds are not transported around the hospital but stay in the wards. The *Acute blood samples* are handled similarly to the Danish case; however, the handling of patient information was more digitalized than in Denmark.

The Japanese cases provided three interesting insights. First of all, the cases helped identify where the analytical framework could be improved. They also gave a good perspective on how the cases' logistical challenges could be solved differently than in the Danish context. Finally, the Japanese cases provided insight into how technology is used in hospital logistical systems in a setting very different from the Danish setting. Four different results were observed after comparing the Danish and Japanese approaches: (1) The Japanese cases generally performed better in terms of controlling patient data (blood sample cases). (2) The Danish cases performed better in terms of controlling non-patient data (*Surgery utensils* and *Bed logistics*). (3) The Danish cases performed worse than the Japanese case in transportation meta-processes. (4) The Danish cases performed better than the Japanese with regard to the use of technology.

The research conducted in Japan presented some difficulties in terms of language. All interviews were conducted using a Japanese professor as translator with the risk that some information would be either missed or misunderstood. This was addressed by presenting and discussing the information obtained from the visits with the professor.

3.3 Data acquired in the research

The information desired from the hospitals involved in this study consisted of two different types of data, qualitative and quantitative.

Qualitative data

Due to the aim of the research, it was important to obtain knowledge of the systems. It was also important to acquire knowledge about what is important in relation to logistics and the use of technology in health care settings. The research methodology used in order to acquire this information was case study research. The main data gathered during the case studies was qualitative data. In this project, two different data collection methods were: 1) observations and 2) interviews.

Observations

On-site observations were used in two different phases of the project. In the initial phase, observations served to gain knowledge about what the hospitals look like inside, how logistical systems in health care settings are constructed, and what is important in terms of quality requirements. In addition, the observations were used to map the working routines and procedures in each of the cases. By using observations, it was possible to determine who does what when.

Interviews

A very important method for gathering data was the use of interviews. As explained in Chapter 1, interviews were conducted with personnel from three different levels in the hospitals: top management, administrative personnel and clinical personnel. In the Danish cases, it was easy to use a semi-structured approach to the interviews, and the semi-structured interviews produced the desired outcome. It was a little more difficult however to conduct semi-structured interviews with the personnel in the Japanese cases. Since none of the involved personnel spoke English at a high level, a translator was necessary in order to conduct the interviews. Therefore, these interviews followed a more structured manuscript in order to ensure that the relevant information was gathered.

Quantitative data

Quantitative data was used for two parts of the research. In relation to the analytical framework, making the process map for each of the logistical systems depended on the use of quantitative data. This type of data was also used for the simulation model. Different types of quantitative data were used to obtain a realistic picture of the logistical system:

- Blueprint of the hospital
    - Create a model of the hospital containing exact distances.
- Measurement of working routines
    - Measure the walking speed of hospital personnel.
    - Determine the time used waiting for elevators and the elevator's transportation time.
- Data extract
    - Number of blood samples taken at the different departments throughout a normal period.
    - Time spent taking blood samples at the different departments.
    - Time spent finishing and leaving the departments.
    - Number of personnel involved in the situation being simulated.

The simulation also produced some quantitative data that was analysed further. The simulation was constructed so that information was gathered about when a blood sample is taken, when the biomedical analyst leaves the department, and when the blood sample is delivered to the laboratory. This made it possible to analyse the data and calculate the following three parameters used to compare the operational performance of each technology:

- Average waiting time (AWT): The average time from when a blood sample is taken until it arrives at the laboratory.
- Maximum waiting time (MWT): The maximum time from when a blood sample is taken until it arrives at the laboratory.
- The distribution of arrivals of blood samples in the laboratory. The distribution of arrivals is displayed as histograms, and the mean and standard deviation of the histograms is calculated as well. The mean is calculated as the mean time of all blood sample arrivals at the laboratory. The standard deviation is calculated as the square root of the average of the squares of the differences between the arrival times and the mean of the histogram.

3.4 Summary

The phases followed in the research have an impact on when the collaborating institutions are involved and to what extent. The main collaborator, Herlev Hospital, was involved in the initial phase when the foundation of the research was developed. The hospital was also involved in testing and validating the model throughout the research. The hospital participated with three different cases: *Acute blood samples*, *Bed logistics* and *Surgery utensils*. Results obtained from analysing *Acute blood samples* were implemented, and results from the analysis of *Bed logistics* are in the initial state of being implemented. In addition, the results obtained in the research have been implemented in the hospital's approach to constructing future logistical systems, as well as changing existing systems. The hospital also had a financial stake in the project by co-financing the research.

Another Danish hospital, Hvidovre Hospital, also participated in the research, but mostly in the simulation part. The hospital was involved in testing the analytical framework in a different setting, as well as validating the results from the analytical framework with those obtained using a simulation model. Furthermore, the simulation analysis provided a foundation for the hospital's current work in changing the procedures used in relation to the case, *Planned blood samples*.

As part of the research, two Japanese hospitals were also involved. The aim of their involvement was to test and validate the framework. Cases in a different cultural setting were used to enhance the generalizability of the model and test whether the model was applicable in different settings. Two cases from each of the Japanese hospitals were involved in the research.

The main type of data gathered in the research was qualitative data. The data was collected through the use of interviews and on-site observations. Both of these two data collecting methods were used in all the cases involved in the research. The interviews conducted with the Japanese hospitals were more structured due to the language barrier. Initially, the data collection helped to give an understanding of how logistical systems are perceived in health care settings. Later in the research, the data was used to test, validate and modify the analytical framework, both in accordance with the Danish cases but also to comply with requirements of Japanese health care. Quantitative data was also collected and analysed in the simulation part of the research. In this part, the data helped to construct a realistic picture of the situation being analysed. In addition, the data helped to evaluate and compare different technological solutions.

Chapter 4 – Analytical Framework

This chapter presents the results obtained during the research with main focus on the analytical framework. As the project developed, the research was presented in three journal articles and three conference papers, each focusing on different aspects of the research. The papers were developed in accordance with the research, with four articles describing the analytical framework and two articles presenting the simulation study. This chapter presents the main results, conclusions and contributions of each article in order to highlight the most important results of the whole study.

4.1 Analytical Framework

This first section of the chapter presents the analytical framework and the development and ideas of the framework that evolved over time. One of the most important parts of the analytical framework is the assessment model. The assessment model was qualitative to begin with and then developed into a quantitative model. Qualitative assessment means that the analysis of the logistical systems is conducted on the basis of some guidelines (e.g. pros and cons regarding different technologie), and the output of the model is descriptive recommendations. The quantitative model's outcome consists of a performance score between 0 and 1, and the performance is obtained using strict performance limits. The research involving the framework was developed while working with four different articles. The first article (P1) presented the basic concepts on which the framework is based, and the initial ideas of how the analytical framework could be constructed. The framework presented in this research is based on qualitative assessment. The second article (P2) presents how the concepts can be transformed into an analytical model. In this paper, the differences in health care between Denmark and Japan are presented, as well as how the model should be transformed in order to be applicable in both health care systems. The third (P3) and fourth (P4) articles present the final framework, and each presents a case in which the framework was used.

The *Acute blood samples* case was discussed in three of the papers. The change in how the analysis was conducted gives a good idea of how the analytical framework was developed throughout the research.

P1 – Basic concept

Title: Improving Hospital Logistics by Rethinking Technology Assessment

The paper was the first paper written during the PhD. during the initial stage of the project when the foundation of the project was not completely determined. The paper presents the early ideas regarding what the framework might look like. The empirical foundation for the paper was the *Acute blood samples*. The assessment of the case was qualitative.

The aim of the paper was to present how an analytical framework can be constructed in order to improve in-house hospital logistics. The framework should consider the entire logistical system and thereby ensure that a holistic overview of the entire system was maintained. Furthermore, the aim was to explain how different technologies could be identified within the logistical system in order to improve efficiency. The paper was mainly focused on sub-question 1.

The basis for the paper was the relationship between the efficiency of a logistical system and four different elements within the system: logistics, technology, structure and procedure.

Conceptual basis of the research

The paper presents the basic concept of the theoretical foundation by presenting the four elements: logistics, technology, structure and procedure, and how they affect the efficiency of the overall system (figure 7).

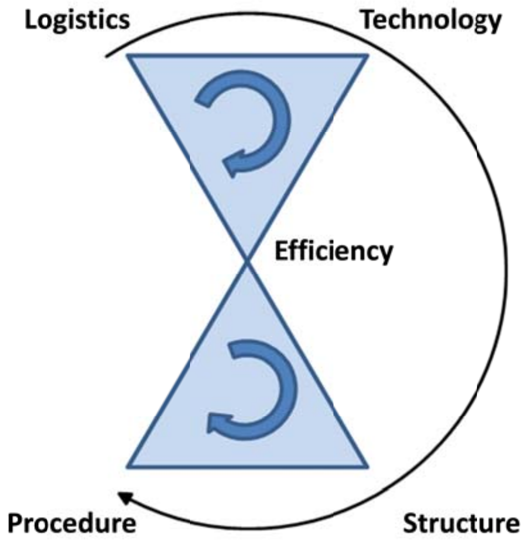


Figure 7: The initial concept of the framework

Figure 7 shows the basis of the framework as consisting of two triangles merged together. Each triangle represents a separate iteration. The first triangle represents logistics, technology and efficiency. The three elements affect each other in an iterative manner. The second triangle represents structure, procedures and efficiency, and also here the three elements affect each other. By merging the two triangles, the relationship between logistics, technology, structure and procedures is illustrated, with efficiency as a resulting parameter.

The different elements in the figure have the following definitions. The *logistics* are mainly controlled by: 1) the distance between start and end point, 2) the quantity moved between the points, 3) the frequency with which the quantity has to be moved, and 4) the speed at which the quantity is moving.

The *technology* is mainly controlled by: 1) the method or principle used, and 2) the medium or tool that is transferring the technology.

The *structure* represents the relation between the following: 1) the division, 2) the hierarchy, 3) the organisation, and 4) existing competences.

The *procedure* refers to the ways in which certain actions and processes are carried out and is expressed by: 1) what the process is, 2) who carries it out, and 3) the sequence of the processes. The procedures can both represent physical actions and the information flow related to another flow, for example a patient flow. The procedure is inspired by the LEAN philosophy (right item, right quantity, right place, right time).

Changes in *efficiency* can be measured and evaluated in many different ways, all depending on the logistical system. Criteria and parameters can be, for instance, lead time, number of handover situations, length of stay (LOS), resource utilization etc.

Qualitative framework

At this stage of the research, the assessment was done in a qualitative manner. The framework was tested on the *Acute blood samples* case, in order to apply the framework, ten different steps were followed:

1. The system was chosen and bounded.
2. The system was described and the overall processes defined.
3. Quality demands and specification requirements were defined.
4. Technological possibilities for each of the overall processes were explored through study of the literature, searching the internet, and brainstorm with employees.
5. The system at the hospital being analysed was thoroughly described using e.g. $IDEF_0$.
6. The processes in which responsibility is shifted from one department to another were thoroughly analysed.
7. A flow chart was created showing the linkage to the overall processes.
8. The structure and related procedures were analysed and described.
9. The flow chart was used, combined with VSM, 5S, and Poka Yoke.
10. The analysis gave a basis for recommending improvements.

The analysis identified four major processes. The technological possibilities within each of the processes are presented in table 2.

Major process	Technological possibilities
Taking the blood sample	- Manual - Automatic
Transporting the blood sample to laboratory	- Manual transport - AGV - Pneumatic tube system - Decentral laboratories
Testing the blood sample	- Manual - Automatic

Transporting the result of the test back to the emergency department	- Physical
	   o Manual, AGV, pneumatic tube.
	- Electronic
	   o Computer, fax, telephone

Table 2: Overview of technological possibilities presented in P1

During step 3 of the analytical framework, some quality issues were identified that were important to be aware of:

- Damage to the blood sample during transportation
- Time between blood taking and blood analysis

- Influence of temperature
- Traceability
- Number of handover situations

In addition, a flow chart of the analysed case was constructed in accordance with the framework.

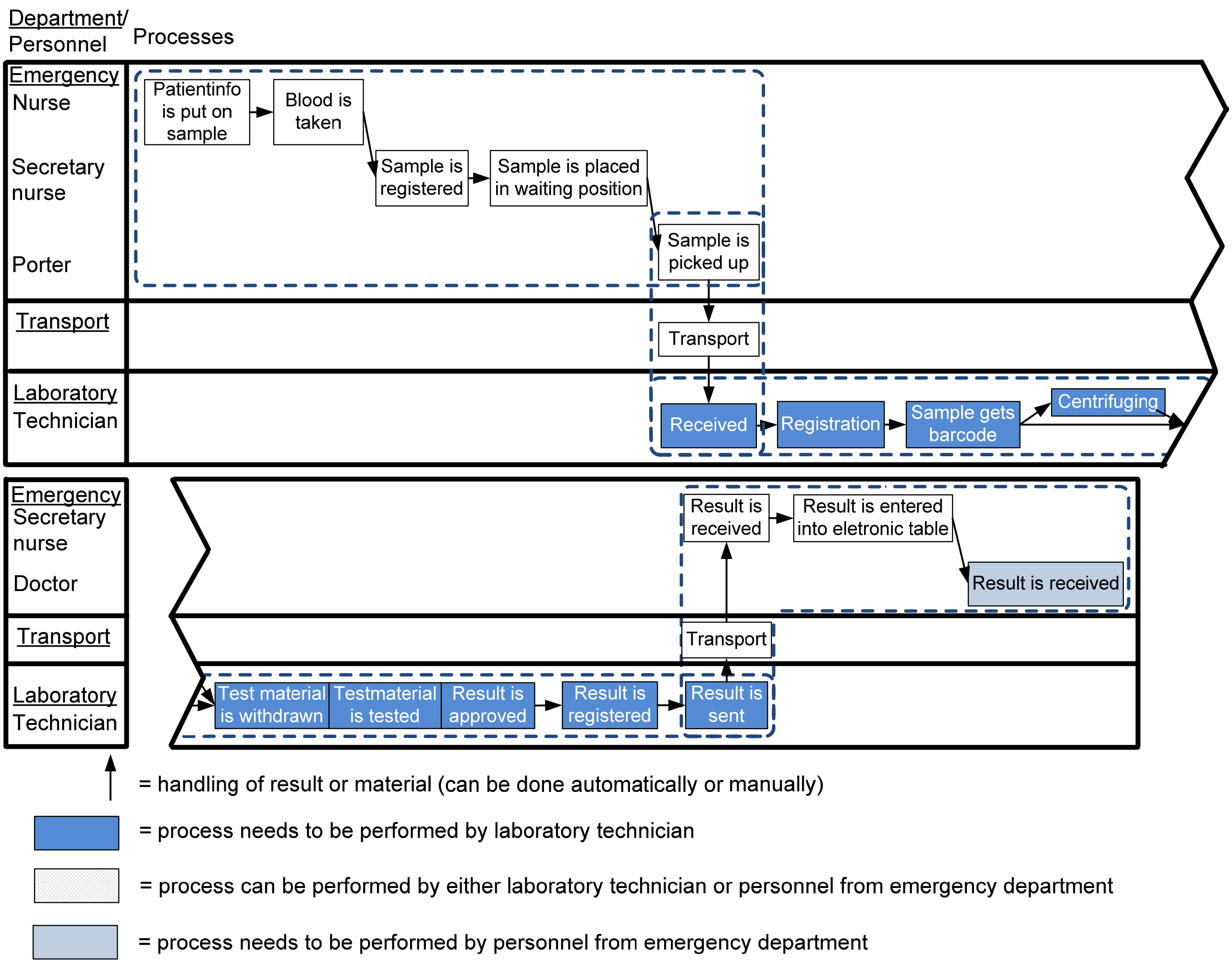


Figure 8: Flow chart from P1 – *Acute blood samples*

The analysis of the logistical system identified some issues on the overall level and for each of the major processes (presented in table 3).

Process	Issues
Overall level	- Too much non-value adding time used in transportation - Feedback of results very unsatisfactory - Unnecessarily many competence shifts in handover situations - Some processes conducted unnecessarily
Taking the blood sample	- Nurses should register the blood samples instead of the secretary by attaching a barcode identifying the patient to the blood samples, which nurses can scan after the blood samples are taken.
Transporting the blood sample to laboratory	- Locating the laboratory and the emergency department close to each other would be an optimal but extremely expensive and unrealistic solution. The best technological solution is therefore a pneumatic tube system, which starts at the emergency department and ends at the laboratory. • The pneumatic tube system works at other hospitals. • The quality of the blood samples is maintained. • This system will decrease transportation time by up to 40 minutes. - The investment will be saved within two years. The system costs approximately €67,000 to install. Two transport porter positions with salaries of about € 27,000 per year each will be saved.
Testing the blood sample	- The analysis is highly automated but attention should be given to the hand-over situations involved in receiving the blood samples.
Transporting the result of the test back to the emergency department	- When the result is received in the emergency department, the personnel responsible for the patient should be notified immediately, instead of having to find the answer themselves. One solution would be to give doctors some form of PDA or notify them by telephone. The device should then be linked to the emergency department system for controlling patients, so the doctor is notified as soon as the result for his/her patient is available, also if the result is critical. Another solution could be large screens in the emergency department showing some kind of alarm when a result is ready.

Table 3: Issues identified using framework in P1

Based on the identified issues the proposed technological implementation was a pneumatic tube system. The paper identifies what effect the implementation of this technology would have within each of the five elements (table 4).

Element	Effect
Efficiency	- The lead time for the blood samples is reduced from about 74 min. to about 51 min. This change would have a big impact on the flow of patients in the emergency department. - The number of handover situations is also decreased from 5 to 3. This lessens the risk of errors. - Patients' length of stay (LOS) is reduced by the same amount as the lead time, about 23 min.
Logistics	- Implementation changes the value stream of the system, eliminating unnecessary activities. - Tests arrive at the lab more smoothly, avoiding the risk of queues.
Technology	- The technology is changed from a purely manual approach to a pneumatic tube system. This is a more reliable system with low maintenance costs
Structure	- In the short term, the change results in eliminating two positions, because porters are not needed to transport blood sample after implementation. - In the long term, the system will probably have some effect on the personnel in the emergency department, because the system is more efficient and the result could be a need for fewer personnel.
Procedure	- Instead of the secretary, the nurses have the responsibility to register the blood samples before sending them. The nurses also have responsibility for informing the laboratory that the blood samples are sent and will soon arrive at the laboratory. The notification will probably be done by pressing a button. - At the laboratory, the personnel need to be aware that samples from the emergency department arrive continuously and not every half hour as is currently the case.

Table 4: Expected effect implementing pneumatic tube system presented in P1

Contribution

This paper laid the foundation for the project by presenting the initial framework and some of the tools to be used in the framework. The framework presented in the paper was inspired by LEAN thinking with many concepts from LEAN included in the analysis approach. The paper proposed a holistic approach to the logistical system.

The analysis and recommendations obtained from using the framework were qualitative, which created the problem that both the proposed issues concerning the current system and the perceived impact obtained from using a new technology have a tendency to be subjective; therefore, it is open to question whether another researcher would obtain the exact same result when conducting the analysis. This problem became evident later in the research and was addressed in P2.

P2 – Constructing an analytical model

Title: Assessing Technology in Hospital Logistical Settings: Comparing Danish and Japanese Health Care.

The paper was written in continuation of the external stay in Japan. The overall aim of this stay was to test whether the model presented in P1 would be applicable to Japanese settings, and how it should be changed to ensure that the model would be more general. The paper presents how the framework was transformed into a more quantitative model with performance measures within the four elements; logistics, technology, structure and procedure. In addition, the paper presents the main differences observed between Danish and Japanese health care when applying the framework. The paper focuses mainly on sub-question 2.

The empirical basis for the paper was four similar cases from Denmark and Japan: *Acute blood samples*, *Planned blood samples*, *Bed logistics* and *Surgery utensils*. Each of the cases were tested and the Danish and Japanese results were compared to provide insight into some of the major differences.

Definition of logistics in health care

The paper is based on the findings and ideas presented in P1. One of the key parts of the paper is a clear definition of the logistical systems focused on in this research (presented in Chapter 1).

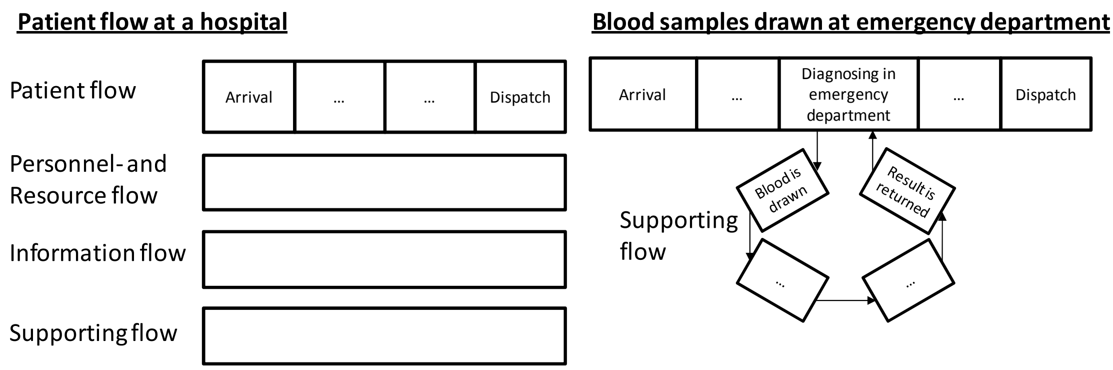


Figure 9: Definition of logistical flows at hospitals presented in P2

The supporting flow can be considered to be a back-office function that is not experienced directly by the patients but is essential for the patient flow to function. As part of the definition of hospital logistics, the concept of meta-processes is introduced. Meta-processes need to be performed for the system to work.

Quantitative framework

The framework presented in P1 was a qualitative framework. Testing the framework in a Japanese context showed that the framework needed to be changed from a qualitative assessment framework to a quantitative assessment framework. Transforming the framework made it possible to calculate performance of the logistical system for the elements described in the conceptual model. The four elements were transformed into measurable parameters, and the parameters divided into indicators. A performance assessment model was constructed using the parameters and indicators. This model made it possible to measure the performance of the Japanese logistical system as well as the Danish systems. Using the new model also made it possible to make a more direct comparison between the two systems and thereby pinpoint differences.

The extended model was based on the principles of performance measurement. The aim of the model was to measure the performance of the current logistical system and assess the potential of implementing new technology. The entire logistical system was assessed using the model, thereby ensuring that the model was holistic. The performance of the current system and the potential for using new technology were calculated using the parameter and indicator structure shown in figure 10.

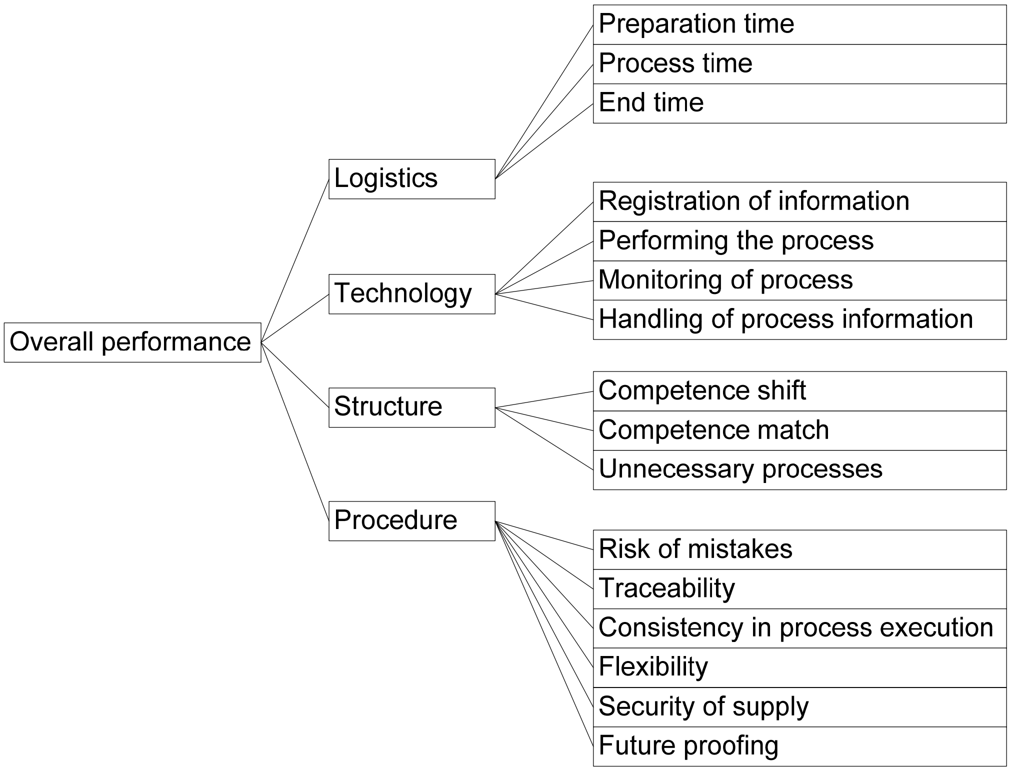


Figure 10: Structure of performance measuring model presented in P2

The performance of the indicators was calculated on a scale from 0 to 1, 0 being the worst obtainable performance and 1 the best. In order to calculate the performance of the parameters and the overall performance, the performance of the indicators was aggregated based on weighting. The weighting was done on a scale from 1-10, 10 being most important and 1 least important. This ensured that the overall performance reflected what the hospital considered most important.

An example of how performance is calculated for a meta-process is shown in figure 11. The performance is calculated using Excel®.

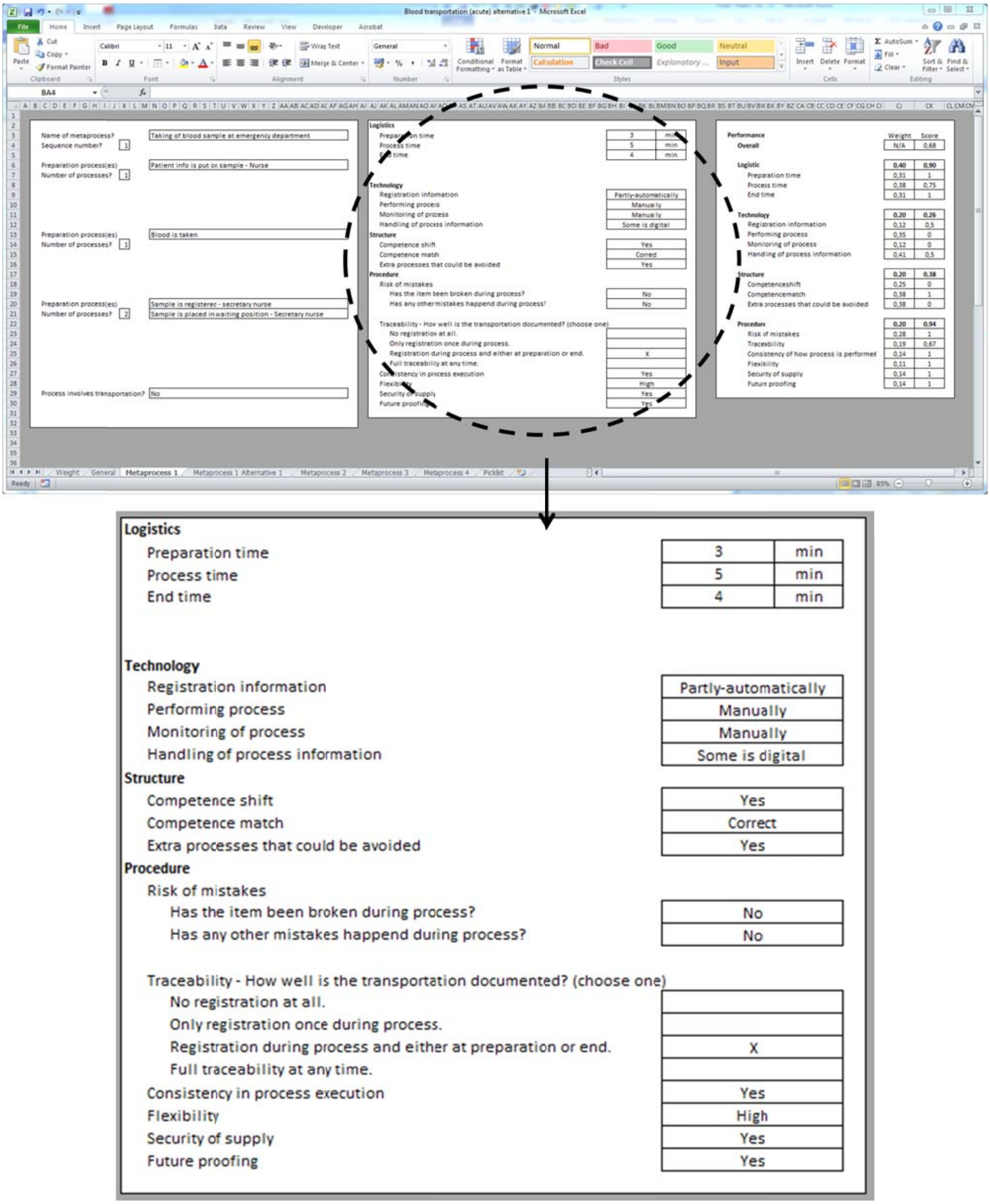


Figure 11: Performance measure of a meta-process

Based on the qualitative assessment framework from P1 and the performance assessment model, nine new steps were developed to be followed in order to obtain an evaluation of the performance of the logistical system being analysed:

1. Identify the logistical system – define which logistical system is to be the aim of the analysis.
2. State the quality requirements of the system – each logistical system has some quality aspects that need to be fulfilled in order to determine if the system is working appropriately.
3. Identify the meta-processes of the system – a logistical system consists of a set of meta-processes, which are the processes that need to be performed for the system to work.
4. Draw a process map for the specific logistical system – based on the specific case and the meta-processes, it is now possible to create a process map that contains all processes, the personnel performing the processes, and the location of the processes.
5. Assess the weights of the parameters and indicators – the parameters and indicators need to have a rating in terms of how important the hospital management considers them to be. The overall performance will thus reflect the relative importance to the hospital. The weights are rated on a ten-point scale from 1 to 10.
6. Fill in the framework for each of the meta-processes – the indicators can now be filled in and the performance of the system can be determined. This is done in a corresponding Excel file.
7. Locate poor performance in the system – it is now possible to locate any poor performance of the system, and thereby determine where new technology will have the biggest impact.
8. Identify possible technologies that can improve performance – in cooperation with hospital employees it is possible to identify technologies that can help improve poor performance.
9. Compare performance of the current and the planned system – the old (current system) and the new (planned system) performance can now be compared, and it is possible to assess whether implementing the new technology makes sense.

The framework ends with a table used to assess the effect of a technological change. An example of this is shown for the *Acute blood samples* case. The effect of implementing a pneumatic tube system for transporting blood samples between the emergency department and laboratory is evaluated.

Overall	Old Performance	0.66	New performance			0.78
Meta-process 2	Old Performance	0.57	New performance			0.97
Meta-process 3	Old Performance	0.71	New performance			0.82
Change in time	Old time (min.)	89	New time (min.)	67	Change (%)	-25

Table 5: Comparison of performance presented in P2 between current system and system after technological implementation

Differences in Danish and Japanese health care

The framework was applied for the eight different cases from both Denmark and Japan, and the main results concerning the differences were the following:

- Japanese cases generally had a higher score in terms of controlling patient data (blood sample cases).
- However, Danish cases scored higher in terms of controlling non-patient related data (*Surgery utensils* and *Bed logistics*).
- Danish cases scored lower than the Japanese case for transportation meta-processes.
- Danish cases scored higher than the Japanese for the technology indicators.

The main reasons behind the differences are the following:

- Sizes of the hospitals. Denmark initiated a health care reform resulting in fewer but bigger hospitals, whereas the Japanese health care system consists of smaller but more hospitals.
- The Japanese health care sector consists of many outpatient clinics, which act as the primary care sector. In Denmark, outpatient clinics are smaller units compared to Japan. As a consequence, the Japanese outpatient clinics are capable of treating more patients than in Denmark, where outpatient clinics' role is to diagnose, prescribe medication and refer patients to treatment.
- In Japan, an integrated information and communication technology (ICT) system is used. As a result, outpatient clinics and hospitals are easily able to access the same system.
- The Japanese hospitals rely to a much greater extent on outsourcing logistical assignments than Danish hospitals. Many of the transportation processes were outsourced to outside companies. This is however something the Danish health care sector is starting to focus on.
- The Danish health care system focuses a lot on documenting everything that happens throughout the system, thus making it easy to pinpoint where mistakes occur, correct the mistake, and repair materials, items or goods affected by the mistake. The Japanese cases did not have the same need for documentation.
- Probably the major difference between the systems was in working routines. In the Danish system, personnel are not expected to work more than 37 hours a week, and if they work overtime employees receive overtime pay, in some cases extra free time. In Japan, there is no overtime pay and personnel are expected to work until there are no more patients, which make the system more flexible than in Denmark.

The impression was that the Danish health care system is more inclined to explore new technological possibilities and try new innovations in hospitals' logistical supporting flows than the Japanese. This tendency, however, is driven more by the differences in the structure of the hospitals and the health care sector than by cultural differences. The different approaches to new technology and innovation within hospital logistics are to a greater extent related to the size and complexity of the hospitals and the cost of labour.

Contribution

The work on the paper resulted in developing the framework into a quantitative framework consisting of ordered indicators and parameters that could be used to assess the performance of the system. The analyses of the cases were conducted using objective performance measures, and the performance was measured on a scale from 0 to 1. This made it possible to quickly locate poor performance and then determine where technological implementations would have the greatest effect. Locating poor performance also made it possible to investigate the cause of the poor performance. This made it easier to identify technologies that could help improve performance. In addition, the different technological implementations could be tested in order to determine the potential of the particular technology in relation to the current situation.

The framework presented in the paper builds on the foundation of the qualitative model presented in P1, and the two models pinpoint the same problems with the *Acute blood samples* case. However, the framework is also tested and modified according to health care settings with very different demands. This enhances the framework's applicability and generalizability. Testing and modifying the model in accordance with the perceptions presented by the Japanese cases secured a stronger foundation for constructing the final model.

P3 and P4 – Final framework and final outcome for two cases

P3 title: Identifying the potential of implementing technologies in hospital logistics: making emergency department diagnosis more efficient

P4 title: Assessing the potential of technology in hospital in-house logistical systems – identifying improvement potential using an analytical framework

P3 and P4 are the last two papers of the PhD. The two papers present the final framework. They focus on different parts of the framework and test different cases. P3 presents the final analysis of the *Acute blood samples* case; and P4 presents an analysis of the *Bed logistics* case. Both papers are based on the empirical material from all the Danish and Japanese cases, although the main empirical input is taken from the separate analyses of the cases. The two papers deal mainly with sub-question 3.

The aim of the two papers was to present every aspect of the analytical frameworks – how they were constructed, what was included, how the performance assessment model was constructed, and how performance was measured for each individual indicator. The papers also present how the indicators were constructed in order to describe an approach that can be used to construct a personalised model.

Conceptual model

The conceptual model on which the analytical framework and the performance assessment model are constructed was finalized (figure 12). It differs from the initial one presented in P1.

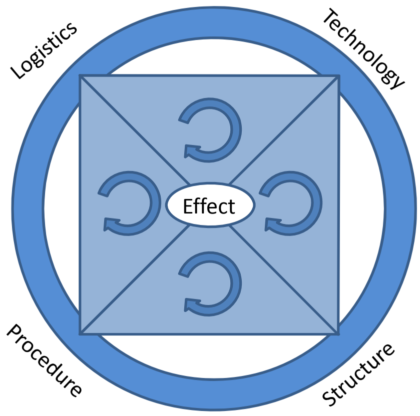


Figure 12: Finalized conceptual model presented in P3 and P4

Logistics refers to the transportation of patients or items during processes. Since not all processes involve transportation of items or goods, the logistical area is not relevant for all processes. For processes involving transportation, the logistics area involves investigating whether it is possible to make the transportation process more efficient. For processes not involving transportation, focus is on the time spent performing the different parts of the process and on the share of inactive time (time where nothing is happening).

Britannica Online (2013a) defines *technology* as "...the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment." Based on this definition, technology is seen as the ability to implement measures that can help employees perform processes in a more automated and less manual manner.

Structure refers to the available competences of the employees and the organisation formed to perform the processes. In this sense, structure is used as an investigative measure to determine whether the organisation is designed to ensure the most efficient process performance. Structure also involves examining whether the correct competences are available in order to perform a given process.

Procedure focuses on how the process has been constructed in order to ensure that the system complies with the quality requirements. Procedure therefore relates both to the risk of making mistakes and to how well the process copes with outside changes that affect the process.

Final analytical framework

The final analytical framework consists of 11 steps and is based on the framework presented in P2. The main difference between the two frameworks is in the changes to the assessment model and that a step eleven has been added.

1. Identify the logistical system – define which logistical system is to be the aim of the analysis.
2. State the quality requirements of the system – each logistical system has some quality aspects that need to be fulfilled in order to determine if the system is working appropriately.
3. Identify the meta-processes of the system – a logistical system consists of a set of meta-processes that need to be performed for the system to work.
4. Draw a process diagram for the specific logistical system – a process map containing all processes can be created using the specific case and the meta-processes as well as who performs them and where they are performed.
5. Assess the weight of the indicators and the performance criteria – the indicators need to be rated in terms of how important they are to the hospital in question, and the performance criteria need to be defined. The overall performance thus reflects the relative importance to the hospital. The rating uses a scale from 1-10.
6. Fill in the performance assessment tool for each of the meta-processes – the indicators can now be filled in and the performance of the system can be determined.
7. Locate poor performance in the system – it is now possible to locate the poor performance of the system and thereby determine where new technology would have the biggest impact.
8. Identify possible technologies to improve performance – in cooperation with the hospital employees, it is possible to identify technologies that can help improve the poor performance.
9. Fill in the performance assessment tool for the proposed technologies – based on the technologies proposed, it is possible to fill in the assessment model and use it to make an estimate of what effect the changes will have.
10. Compare performance of old and new system – the old and new performance can now be compared, and it is possible to assess whether implementation of new technology makes sense.
11. Assess feasibility of the changes planned – it is possible for the hospital to make an assessment of the proposed technological changes in terms of the cost of implementing them. By combining this assessment with the projected benefits in performance, the hospital can then decide whether to implement the technological changes or not.

The eleven steps of the framework can be grouped into three different groups. Steps 1-7 focus on defining and analysing the current setup. Steps 8-10 are part of idea generation, which aims to improve the current setup. Step 11 explores the possibility of implementing the ideas, and the financial aspects involved in the implementation. Step 11 is executed by the hospital management using the outcome from the first ten steps as supporting information for deciding whether or not to implement a technology, and which technology will have the biggest impact.

Final performance assessment model

The final performance assessment model is also based on the concepts presented in P2. However, the structure of the model is changed. The structure of the performance assessment tool is based on the concepts from OEE (overall equipment efficiency). The overall performance is calculated using the performance of the elements on the basis of a set of indicators (see figure 13).

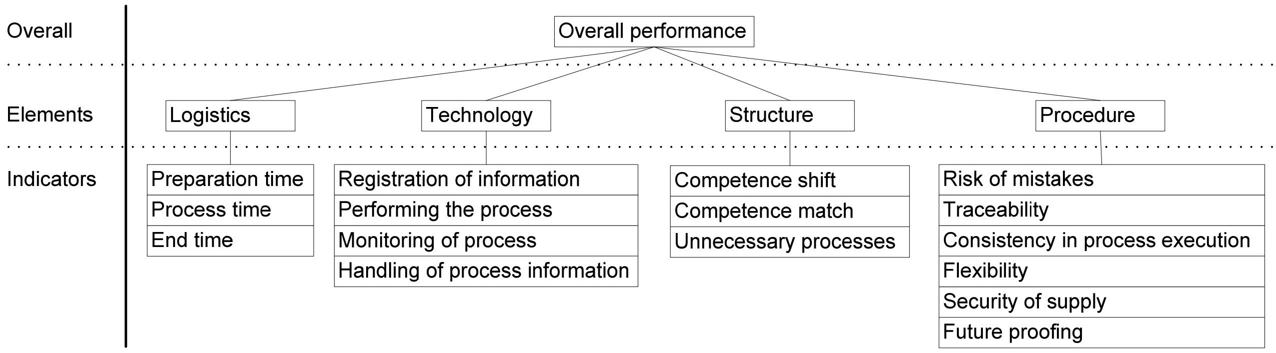


Figure 13: Performance hierarchy

An indicator can be characterized by five attributes; (1) the name, (2) the element under which it is located, (3) the corresponding category, (4) the performance assessment question (Q_x), and (5) the performance assessment criterion. Figure 14 shows the indicator matrix, containing all the indicators and the attributes for each indicator.

	Element 1		**...**	**Element k**
	Indicator 1	**Indicator 2**	**...**	**Indicator i**
Category 1	Q_1 Evaluation criteria$_1$		...	
Category 2		Q_2 Evaluation criteria$_2$	...	
...	...	...	...	...
Category j			...	Q_i Evaluation criteria$_i$

Figure 14: Indicator matrix

Each indicator is assigned an *indicator name*, and located under an *element*. The current research operates with four elements: logistics, technology, structure and procedure.

Each indicator is assigned to an *indicator category* according to how the performance is calculated.

In order to calculate the performance of the indicators, each indicator is assigned a *performance assessment question*. The way the answer is obtained depends on the category of the indicator.

In order to calculate the performance of the indicator, the *performance evaluation criterion* is determined. The performance of each indicator is calculated on a scale in which 1 is the best obtainable result, and 0 is the worst. The performance assessment criteria vary according to the indicator category. For some categories, the extremes can be yes or no, and for others the extremes can be measurable limits.

In this study, 16 indicators are identified (see figure 13), and five different indicator categories are created. The categories are: (1) Time measurement: performance is measured as the ratio of inactive time to overall process time for the particular meta-process. (2) Observation: performance is measured by exploring how the process is performed and then assessing whether the observed procedure is in accordance with the performance assessment criteria. (3) Process analysis: performance is measured using the process map created for the supporting flow. (4) Data extract: performance is measured using data that can be extracted from the hospital databases. (5) Assessment: performance is determined by assessing whether the meta-process is in accordance with the requirements posted for the indicators belonging to this category. In order to carry out the assessment, inside knowledge of the process is needed.

Figure 15 shows the indicator matrix created for all the indicators within the structure element. All five categories are easily obtainable from the indicator matrix.

	Structure		
	Competence shift	**Competence match**	**Avoidable processes**
Time measurement			
Observation	**Does responsibility for the process change during the process?** 0 | ——————| 1 Yes No	**Is there a match between necessary personnel qualifications and actual competences?** 0 | ——————| 1 Lower Higher Fit	
Process analysis			**Do the meta-process contain unnecessary processes?** 0 | ——————| 1 Yes No
Data extract			
Assessment			

Figure 15: Example of indicator matrix for the element *Structure*

The performance assessment criterion is central for measuring the performance of a meta-process within the different indicators. It is therefore important to understand the construction of the performance assessment criteria. The performance assessment criterion for the indicators *Preparation time* and *Registration of info* is presented in figure 16.

Logistic – Preparation process

Score	0	0,2	0,4	0,6	0,8	1
Criteria	> 50 %	40 – 50 %	30 – 40 %	20 – 30 %	10 – 20 %	< 10 %

Tecnology – Registration of info

Score	0	0.5	1
Criteria	Manual	Partly-automatic	Automatic

Figure 16: Performance assessment criterion for the indicators *Preparation time* and *Registration of info*

Figure 16 shows the performance assessment criterion for two very different indicator categories, namely *Time measurement* and *Observation*, and as a result, the criteria are very different. However, using the performance criteria makes it possible to compare performance within the two categories. Since the performance criteria are very important for comparing the performance of two different indicators, it is crucial that the performance criteria are carefully chosen and thoroughly evaluated in order to obtain as true a picture as possible.

In order to apply the performance assessment tool comprehensively and investigate the benefits of implementing a new technology, a structured approach was developed, and an analytical framework constructed.

Case analysis

The analytical framework and the performance assessment model were applied to two different cases and gave reliable results that have been adopted. The two analyses show that the framework and model are applicable to various settings.

Acute blood samples

The main results from the analysis gave the following results concerning the meta-processes and the overall level, and are similar to the results presented in both P1 and P2.

Process	Performance
Overall	0.64
Taking of blood sample at emergency ward	0.61
Transporting blood sample to laboratory	0.43
Analysing blood sample	0.91
Transporting result to emergency department	0.61

Table 6: Performance of *Acute blood samples*, presented in P3

The following technological changes were identified based on the analysis of poor performance.

1. A system was implemented so that nurses can scan blood samples quickly and easily after taking them.
2. A pneumatic tube system was installed for transporting blood samples between emergency department and laboratory.
    - Presuppose implementation of pneumatic tube system, implement a machine so samples are placed directly onto the conveyor system of the laboratory analysis machines, and use the barcodes already attached to the samples.
3. The result is sent directly to the doctor, who receives the result on a portable device.

The assessed performance of the different technologies gave the following results:

Technology	Performance
Current	**0.64**
Technology 1	**0.69**
Technology 2	**0.73**
Technology 2 (incl. machine at laboratory)	**0.75**
Technology 3	**0.72**

Table 7: Assessed performance of the technological implementations for *Acute blood samples* presented in P3

Bed logistics

The main results from the analyses gave the following results concerning the meta-processes and the overall level:

Process	Performance
Overall	**0.57**
Bed is transported to patient	**0.54**
Patient is placed in bed, which is now in use	**0.59**
Patient is discharged and leaves bed	**0.68**
Bed is transported to cleaning	**0.51**
Bed is unmade, then cleaned and made	**0.51**

Table 8: Performance of *Bed logistics* presented in P4

The following technological changes were identified on the basis of the analysis of poor performance:

1. A tracking system implemented to ensure complete overview of the position of the beds.
2. A system implemented so the beds can be registered as clean or unclean in order to make it possible to identify the location of unclean beds. This system requires that technology 1 be implemented.
3. Robots used to transport empty beds; requires implementation of technology 1 and 2.

4. Automatic washing and cleaning system for the beds implemented.
5. A more flexible type of conveyor belt system used for transportation of beds in cleaning area, for example some type of moving walkway.

The assessed performance of the different technologies gave the following result:

Technology	Performance
Current	**0.57**
Technology 1	**0.71**
Technology 2 (incl. 1)	**0.74**
Technology 3 (incl. 1 and 2)	**0.87**
Technology 4	**0.63**
Technology 5	**0.61**

Table 9: Assessed performance of the technological implementations for *Bed logistics* presented in P4

Contribution

The articles are the final outcome of the research and present the final analytical framework and performance assessment model. The articles establish the final definition of the conceptual model, thus laying the foundation on which the project is based. The framework offers a very structured approach to conducting the analysis of the system, while ensuring that both the overall picture of the system and the possibility to identify issues on a process level are maintained. This ensures that the system is not sub-optimized and that there is a focus on cross-departmental interfaces. The construction of the indicators is thoroughly presented, and the papers explain what should be considered when constructing indicators.

As a result of the very structured approach, the articles deal with how to tackle the obstacles to implementing technologies, by tracking the impact on performance within different elements. This issue was addressed by using two different steps: The first step involves the idea generation of the framework: 1) identifying weak performance, 2) proposing technologies that address the weak performance and 3) assessing the impact of implementing the technologies. This is followed by the step of addressing the economic feasibility of the technologies. Having a full overview of the perceived impact of the technologies provides a very good basis for starting the economic analysis and helps hospital managers decide whether or not to proceed with implementation. Based on the framework addressing this issue, the model is to be used to guide Herlev Hospital in conducting analyses of the logistical system in the future. The results from the two cases analysed and presented have been adopted by the hospitals involved and are currently implemented or in the process of being implemented.

4.2 Simulation model

Concurrently with the development of the analytical framework and the performance assessment model, a simulation project was conducted. This was done to investigate a different approach than the analytical framework in order to explore possibilities for improving logistical systems by using different technologies. The simulation projects are described in two papers (P5 and P6) that explain how a simulation project should be constructed and what the most important issues are when constructing simulation projects. P5 is based on two cases: *Acute blood samples* and *Planned blood samples*. P6 focuses only on *Planned blood samples*. P5 presents the results from the two different cases, whereas P6 describes in more detail the procedures conducted in constructing the simulation project.

The two papers were written simultaneously, so some parts are identical, but the scope of the two papers is different. P5 focuses on a more conceptual level of the potential of simulation, whereas P6 focuses more on how simulations are constructed and what to consider when constructing them.

In the following, the two articles are presented, and the most important aspects of each of the papers are described. The aim is to present the basis for constructing the simulation model, the results obtained, and the most important aspects of conducting simulation studies.

P5 and P6 – Simulation model

P5 title: Improving Blood Sample Logistics using Simulation

P6 title: Identifying the Potential of Changes to Blood Sample Logistics using Simulation

Constructing the simulation models

Before starting the construction of simulation models, it is important to have a clear picture of the aim of the simulation. P5 formulates four different aims, all focusing on evaluating how to improve the system:

1. In which parts of the system is the major time consumption?
2. Which of these processes are possible to change?
3. Identify different technologies can perform the process.
4. Determine the effect of making the changes to the system.

P6 focuses more on how to construct the simulation, which resulted in two aims:

1. How can a discrete event simulation model be constructed in order to represent the current situation at the hospital?
2. What effect will be obtained after changing the procedure for performing blood-taking rounds?

After stating the aim of the simulation project, four steps were formulated as the guiding principles in creating the simulations:

- Construct a process map for the situation to be simulated
- Determine parameters to be measured in the simulation

- Determine the alternative scenarios to be tested
- Gather information regarding all of the processes involved in the process map.

Figure 17 presents the process map can for *Acute blood samples*, as it looks like at Herlev Hospital.

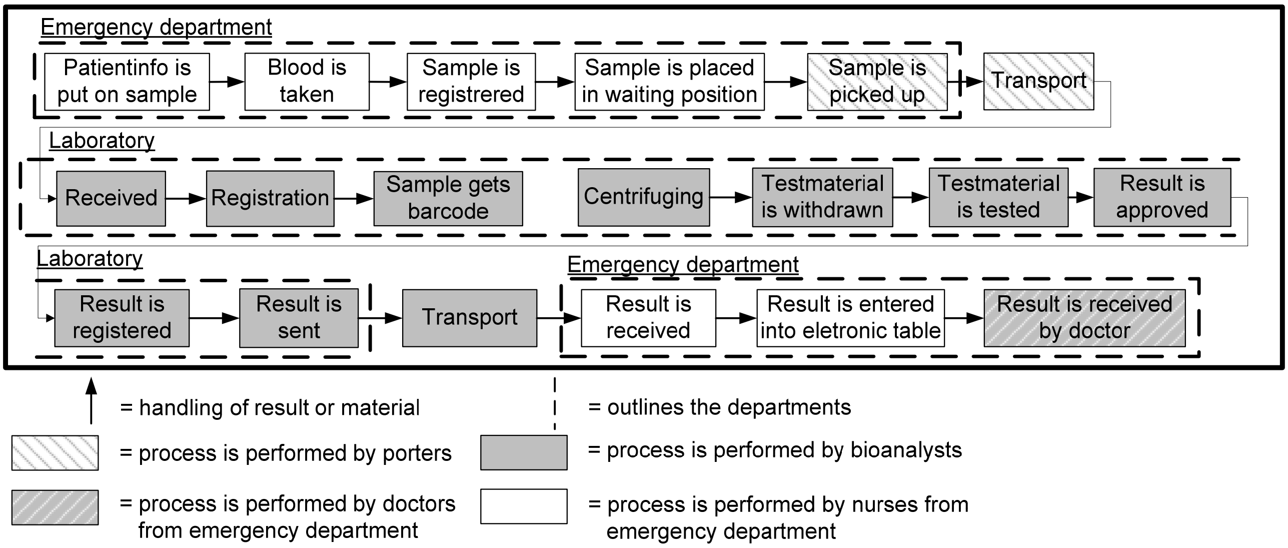


Figure 17: Process map for *Acute blood samples* presented in P5

Two parameters were used for the *Acute blood samples*:

- Average waiting time (AWT): The average time elapsed from a blood sample is drawn until the result of the analysis is received at the emergency department.
- Maximum waiting time (MWT): The maximum time elapsed from a blood sample is drawn until the result of the analysis is received at the emergency department.

Three parameters were used as performance measures in the simulation of the case *Planned blood samples*.

- Average waiting time (AWT): The average time elapsed from a blood sample is drawn until it arrives at the laboratory.
- Maximum waiting time (MWT): The maximum time elapsed from a blood sample is drawn until it arrives at the laboratory.
- The distribution of arrivals of blood samples to the laboratory. The distribution of arrivals is displayed as histograms, and the mean and standard deviation of the histograms is calculated as well. The mean is calculated as the mean time of all blood sample arrivals at the laboratory. The standard deviation is calculated as square root of the average of the squares of the difference between the arrival times and the mean of the histogram.

In the current research project, focus is on testing and comparing different technological scenarios with the current situation. The alternative scenarios were determined in close collaboration with hospital personnel. In testing the different technologies, it was also important to determine the amount of resources used for each technology. In both cases, the following three technologies were tested:

- Manual
- Pneumatic tube
- AGV robots

After determining the technologies the next step was to decide on the amount of resources used, e.g. 1 or 2 AGV robots. This process involved determining at what point an increase in resources would not reduce the AWT and MWT with more than 10 %.

The last step was to gather the information and construct the simulation, and then compare the results obtained for each of the technologies.

In both of the simulation projects, the pneumatic tube system performed best. Tables 10 and 11 present the results obtained in the two papers. For AWT and MWT, the improvement in percentage compared with the current situation is given.

Scenario	Current	AGV	Pneumatic	Pneumatic and receiving robot
AWT	1:27 (N/A)	1:14 (15 %)	1:00 (31 %)	0:51 (41 %)
MWT	1:58 (N/A)	1:43 (13 %)	1:26 (27 %)	1:20 (32 %)

Table 10: Results obtained for *Planned blood samples* presented in P5

Scenario	Current	AGV	Pneumatic	Porter (call)	Porter (45)
Distribution	(9:38, 23)	(9:31, 27)	(9:19, 27)	(9:23, 27)	(9:41, 22)
AWT	1:06 (N/A)	0:55 (16.4 %)	0:43 (35.8 %)	0:47 (29.4 %)	1:08 (-3.0 %)
MWT	1:58 (N/A)	1:40 (15.1 %)	1:36 (18.2 %)	1:35 (19.4 %)	1:36 (18.3 %)

Table 11: Results obtained for *Planned blood samples* presented in P6

Concerns when making a simulation

Validation of the results is a very important issue when making simulations. Does the simulation present a realistic model of the real system? In the current simulation projects, this was approached through establishing very close collaboration between researchers and personnel at the hospital. All the input and output parameters were discussed and decided by the researchers and the hospital personnel. The researchers studied the working procedures of the medical laboratory technicians, and the resulting flowchart of the processes was verified by the personnel. In addition, experiences and information regarding the alternative scenarios were acquired from national and international settings.

The verification process contains two steps: (1) Examining the results from the simulation and comparing them with data extracted from databases at the hospital. (2) Discussing and validating the results at meetings with hospital personnel.

When the simulation model representing the current situation was approved, the work with the different scenarios starts. The results from the different scenarios are presented at regular meetings with the hospital, verified and validated. In both simulations, the Department of Clinical Biochemistry played a very important role. At the meetings with the Department of Clinical Biochemistry, the head of the department, two medical laboratory technicians and the IT-administrator were present. In this way, the simulation model, the data from the model and the procedures were verified at all the organisational levels involved.

All process data was gathered from the hospital, and normal distributions were created for all processes.

Twenty-five runs were performed for each simulation, and the average results from the runs used to make the results more accurate.

Contribution

The simulation project was conducted simultaneously with the development of the analytical framework. Simulation is a powerful tool when analysing operational settings and testing the effect of changes. The use of simulation in this project had two aims: first, to present a different approach to how to analyse hospital logistics and evaluate various technological solutions; second, to test whether the result of the simulation is in line with that of the analytical framework.

Simulation was used on two of the Danish cases, *Planned blood samples* and *Acute blood samples*. In both cases, the main focus was on how the transportation process in each case could be improved by using different technologies. The parameters used to determine which technology was best were related to the time elapsed from when the blood samples were taken until the result is ready. In both cases, pneumatic tube systems were identified as the most optimal solution. This corresponded with the results obtained from using the analytical framework. Although the measures used to determine which technology was best were not the same, the results were used as a means to verify the results obtained from the analytical framework.

4.3 Summary

The chapter presents the results obtained in the course of the research in order to address the research questions. This is done by presenting each of six articles and the most important results and main contribution from each article.

The chapter is divided into two parts. The first main part focuses on the analytical framework developed during the project, which is tightly linked to the research question. This part of the chapter presents papers 1 to 4. The second part of the chapter presents a simulation project conducted simultaneously with the development of the analytical framework. This part of the chapter presents articles 5 and 6.

Paper 1 was written during the initial stage of the project, and presents the early ideas about what the framework might look like. The focus of the paper was sub-question 1. The paper describes how an analytical framework can be constructed in order to improve hospital in-house logistics. The framework was to consider the entire logistical system, and thereby ensure that a holistic overview of the entire system was maintained. The paper also explains how the analytical framework can be used to identify technologies that can improve the efficiency of the logistical system. The analytical framework was based on the idea that a relationship exists between the efficiency of a logistical system and four different elements within the system: logistics, technology, structure and procedure.

Paper 2 took its starting point in the results obtained and presented in paper 1, and focused mainly on sub-question 2. The paper was developed after the external research was conducted in Japan. The aim of the paper was to test whether the model presented in paper 1 was valid in a completely different context. The outcome was that the model was developed from a qualitative assessment model into a quantitative assessment model. The paper also presents the ideas behind the performance measures that are used when assessing the current system and the effects of the different technological changes. The performance measures were grouped within the four elements. The paper gives a clear definition of the hospital logistical system and shows how a patient flow initiates other flows, which are necessary for the patient flow to function optimally. As part of the definition, the concept of supporting flows was introduced, and thus precisely the logistical systems that are the focus of this research.

Papers 3 and 4 present the final analytical framework and mainly address sub-question 3. Besides presenting the model, the two papers each present a case to which the model was applied. The two cases are the *Acute blood samples* and *Bed logistics*. The final analytical framework consists of 11 steps grouped in three parts with focus on different parts of the optimisation process. Steps 1-7 focus on analysing the current setup. Steps 8-10 focus on idea generation for improving the current setup. Step 11 explores the possibilities for implementing the ideas, and the financial aspects involved in implementation. The papers present the final performance assessment framework, which consists of measurable indicators based on the performance measures presented in paper 2.

Papers 5 and 6 present the simulation project. The papers present the construction of the simulation models and how the different technologies were evaluated. Two different cases were included in the simulation project, *Planned blood samples* and *Acute blood samples*. Paper 5 presents the results from the two cases, whereas paper 6 focuses only on *Planned blood samples*. The simulation project was conducted in order to test another approach for analysing hospital logistical systems and evaluating different technologies. In addition, and more importantly, the simulation was used as a means to test whether the results obtained using the analytical framework were in line with the results of the simulation. Although the simulations primarily used time measures, and the analytical framework had more quality aspects, the two approaches gave similar results.

Chapter 5 – Discussion

When conducting research, some concerns inevitably arise. For instance, how valid or reliable are the results? What would the result of the research be if different empirical material were used? This chapter considers some of these issues, first, by discussing the research question and then the contribution of the research.

5.1 Alignment between expected and actual outcome

One issue that researchers need to be aware of is that the research design has a big influence on the outcome of the research. It is therefore very important to elaborate on the research design and the results obtained in the course of the research – for instance, would the same results be obtained using a different approach? The overall aim of the research is to investigate the potential of implementing new technologies in hospital logistical systems. In order to fulfil the aim of the research, three research questions were developed. In the following, the three research questions are discussed in relation to the methodology used and the empirical material as well as the obtained results and the expected outcome.

Sub-question 1 – theoretical foundation for research

What are considered the most important aspects when dealing with technological implementations in health care logistics?

The initial sub-question deals with the foundation of the research and the theoretical basis for the analytical framework. On an overall level, the question deals with technology implementations in health care logistics. But the question can be divided into two parts. One part is related to what are the important issues when implementing technology in health care settings. The second part concerns the important issues involved when making changes to health care logistics. In order to address the question, two different methodologies were used: interviews and discussion with Herlev Hospital's management with focus on their views on the topic; and a literature survey of technology and logistics in health care. The theoretical foundation for the analytical framework was developed in relation to the research question. The logistical systems were analysed and the technological solutions evaluated in relation to four main elements, since it could be established that a system's efficiency was influenced by the technology used, the logistics involved, the procedure used to execute the system, and the structure (typically personnel) put in place to support the execution. This sub-question is primarily dealt with in paper 1.

Assessing the research question on the basis of interviews and the literature survey poses two concerns that need to be addressed. The first issue relates to how generic the theoretical foundation is. Is the theoretical foundation developed through using the interviews generically? Or is it a model that is only applicable for one particular hospital? Herlev Hospital was the only hospital involved in this part of the research. At that stage, they were focusing on how to improve logistics by using technology and already had some ideas and perceptions about how to deal with this question. They therefore had some inputs related to the theoretical foundation that cohered with the initial ideas of the researchers. The foundation of the project was thus affected by the ideas and the experience they had, which carries the risk that the later research based on this foundation would develop into a 'Herlev model'. The theoretical foundation developed by the researchers contained some of the ideas presented by the hospital personnel, but some inputs and ideas were completely new to the hospital. They were quickly accepted, however, as well argued points.

The second issue is that Herlev Hospital had identified a lack of research and literature dealing with the use of technology and logistics in health care. The risk exists that when making the literature survey, the researcher is biased towards accepting this finding and tries to prove it, even though there may be some literature that actually deals with this topic. The literature survey was conducted meticulously. The researchers' perception is that the survey was thorough and provided a comprehensive overview of research in the field, although the risk of missing some important article is always present.

In addition to the concerns identified in relation to the methodology and empirical material, some additional issues were identified. One was whether the four elements and the effect cover all aspects, or if other elements should be added. This issue was addressed through a very close dialogue with Herlev Hospital in the construction phase and with other hospitals in the testing, modification and verification phases, thereby ensuring that not only one hospital influenced the model. The problem exists, however, that when the model is presented to other hospitals, they might perceive the elements as final and refrain from recommending changes. A last question in relation to whether the four elements are comprehensive enough is whether the personnel fully understand what each element covers. This could create a problem, if they think an area that is importance to them is covered even though it might not be.

An overall motivation for the project is the pressure on hospitals to become more efficient so they can deliver the same or a higher level of health care at lower cost. In this respect, it would seem natural to include economy as an element in the foundation of the model. It was decided however that the focus of this research is to improve the logistical systems in order to make them more efficient and deliver improved quality. Ultimately, it is perceived by the researchers that these two issues can help achieve the aim of delivering better health care at the same expenditure level or lower. Later in the course of the research, however, an economic assessment of the technological solution was added to the analytical framework, thereby including economic considerations in the final evaluation of the proposed technologies.

LEAN was identified as a widely used concept in health care to address different operational challenges, and the concept therefore has some overlaps with the current research. One aspect of LEAN, improvement of existing systems, is similar to part of the aim of this research; therefore, ideas and concepts from LEAN served as inspiration in constructing the foundation for the research, even though the word LEAN is not used directly.

Sub-question 2 – construction of a framework

How can a framework be constructed that contains the relations between logistics, technology, structure and procedure and still maintains a holistic overview of the system?

Using the theoretical foundation established in relation to sub-question 1, the aim of sub-question 2 was to transform the concepts from the theoretical foundation into an analytical framework that could be used to analyse a logistical system and evaluate different technologies. The research resulted in an analytical framework containing nine steps and a quantitative assessment tool. The analytical framework provides a method making it possible to analyse a hospital's logistical system and propose some technologies that will help improve the system. This research question is addressed primarily in paper 2.

The research question is addressed using eight different cases. The initial part of the framework was developed in a Danish context and was later tested in a Japanese context. The Danish hospitals were therefore involved in the very early stage of the research. They had complete insight into the foundation of the research and had confidence in the way the assessment of the logistical systems was conducted. Applying the framework to the Japanese cases revealed the need for a very precise description of how the logistical system performed. As a result, the quantitative assessment model was developed. The quantitative model made it possible to precisely determine how the system performed and how the performance was measured. If the analytical framework and assessment tool had not been tested and modified using the Japanese cases, the chance exists that the assessment model would have continued to use a qualitative approach to conducting the analysis. At the time of the external stay in Japan, however, the researchers were in the initial stage of considering whether the model should be transformed into a quantitative model. The indicators were developed, based on information from Herlev Hospital, but with inputs from the Japanese hospitals and Hvidovre Hospital. This was done in order to ensure that the model would be applicable, not only to one hospital but to a wide variety of hospitals. Whether the indicators would have been different if different hospitals, or collaborating hospitals from different countries, were used is difficult to judge. In any case, using a different empirical foundation would not change the focus of the indicators and would probably be similar to those presented in this research.

Constructing the quantitative assessment model raised some concerns. One was related to the construction of the performance measurement tree, with the overall performance divided into four different areas (the four elements) and with indicators within each of the areas. It was extremely important for the indicators to be comprehensible. It was crucial that the process of deciding which indicators are to be used to measure the performance of the system, and how the performance within each of the indicators should be measured, is carried out meticulously. In the current project, the indicators were defined in cooperation with Herlev Hospital. This constitutes a risk that the indicators are only valid in the cases from Herlev Hospital and not other cases. Although the indicators were discussed with the personnel involved in the other cases, the risk exists that they would perceive the indicators presented to them as final, as was the case with the four elements. In addition to discussing the indicators, the performance of the different logistical systems was presented and discussed with the personnel, in order to test whether the results were in line with their expectations. If the results contradicted their perceptions – e.g. if a system had a high performance while the personnel had the perception that the system was not functioning optimally – the personnel would probably have some doubts about the validity of the assessment model. This was not the case, however, and it was therefore hoped that the chosen indicators provided an accurate assessment of the performance of the system.

There were some other concerns in relation to the indicators, in continuation of the concerns regarding ensuring the correct choice of indicators. Performance assessment models with a similar structure to this one raise the issue of correlating some indicators. If a technology is implemented in order to enhance performance within one area, performance might decrease for one indicator or increase for another. Understanding how indicators are related gives an idea of how the mechanisms of the assessment tool work, making it possible to modify the model so that it provides a better assessment of system performance. It was unfortunately not possible to investigate this issue further.

Sub-question 3 – making the framework into a reliable tool

What are the implications in using such a framework in practice and implementing the technologies?

The final part of the research was to develop the framework and assessment tool so that they could be applied on a real-life case and provide a reliable picture of how the system functions today and how it can be improved. This part resulted in the final analytical framework, and the performance assessment tool was developed. Furthermore, a full analysis of two different cases was conducted in order to describe the functionality of the framework and the tool. The final framework and the final application in the two cases are presented in papers 3 and 4.

Sub-question 3 relates to the final part of the research and focuses on combining the theoretical foundation, the initial analytical framework and the assessment tool into a framework and tool ready to be implemented. One of the main aspects of the question is ensuring that the final analytical framework and assessment model can be applied to a wide variety of cases. The research is based on four different types of cases from two different countries, a total of eight cases. The final model was applied in two different cases, *Acute blood samples* and *Bed logistics*, and the results from the analyses are now implemented/being implemented in these specific cases. The fact that the results were accepted and implemented so completely serves as strong validation of the analytical framework and assessment model. In the case, *Acute blood samples*, at Herlev Hospital the proposed changes were adopted, and the expected benefits were in line with the actual benefits. This further supports the final framework and supports the validity. If different empirical material were used (e.g. a case from a hospital less eager to implement changes), the model would not have been validated in this way. Actually observing the consequences of an implementation helps to understand the framework and how it should be modified for future use.

One concern in relation to the final model was that the hospitals accepting and implementing the results were only Danish cases. As stated previously, the Danish cases had an interest in such a model in order to investigate the potential for implementing new technologies. It could have been very interesting if the analysis of the Japanese cases, or analyses of hospitals in other countries, had resulted in changes or implementation of the proposed technologies. Although the verification and modification has been very thorough, also in the Japanese hospitals, it would strengthen the final framework if the results had also been implemented.

In addition to the analytical framework, a simulation study was conducted. The results from the simulation study were especially important in the final development of the framework, because it was very important that the results from the simulation were in accordance with the analytical framework. Using simulation as a verification tool, though, did pose some additional concerns. For example, does the simulation present a trustworthy model of the system being simulated? It is therefore extremely important that a thorough process of validation and verification of the simulation model is conducted. This was accomplished through close dialogue with the personnel involved in the systems being simulated to make sure that the simulation of the current system was completely in accordance with results from the actual system.

There were some concerns about the final framework in relation to the last step, the economic assessment. The most significant change to the framework, compared with the initial framework presented in relation to sub-question 2, was the inclusion of a step involving an economic assessment of the proposed change. The analytical framework ends by assessing the technology's performance and the economic consequence of its implementation. The economic assessment can be divided into two different parts. One part relates to the direct cost of implementing a new technology and the direct operational costs that are affected. In this part of the economic assessment, the directly measurable short-term effect is investigated and estimated. The economic assessment addresses the costs related to installing the technology, the savings in terms of personal etc. The second part of the economic assessment involves the indirect impact of the implementation. This assessment investigates the economic effect of a decrease in errors or time due to the implementation of the technology in the logistical system. The economic evaluation is important, because without some sort of reduction in cost, it is difficult to justify why the technology should be implemented even though it may improve other aspects of the system's performance. The analytical framework and the assessment tool were developed during this three-year project; however, the scope of the research did not include how to conduct the economic assessment, even though its importance was acknowledged. It could therefore be interesting to examine more deeply how an economic assessment model can be constructed, and how such a model could enhance the outcome of the analysis obtained from the framework.

Although the economic evaluation examines both the direct and indirect impact, it can be difficult to be certain whether all relevant aspects of an implementation are considered.

Implementation of a new technology can often have operational consequences for other parts of the hospital than the part being studied. During the analysis of the *Acute blood samples* case at Herlev Hospital, discussions between researchers and hospital personnel identified that implementing a pneumatic tube system would also affect the laboratory. The daily working routines could be optimized due to a more even intake of blood samples, which would result in more efficient procedures. Identifying the exact outcome is difficult, however, so it is important to be aware that additional improvements can be necessary.

5.2 Contribution

Besides discussing the research questions, it is also important to investigate the research's contribution, both scientific and practical. The scientific contribution relates to the achievements in relation to the research community, as well as to determining whether the theoretical results are reliable and valid. The practical contribution relates to whether the results are applicable and general, as well as to the practical impact of the research.

Scientific contribution

Besides addressing an issue presented by Herlev Hospital, the research also aimed to contribute to the scientific community. On the overall level, the research generated three scientific contributions. The first contribution concerns the research gap. As presented in the introductory chapter, a gap was found in the literature regarding the use of technology within logistical settings in health care. The research addresses this gap by developing a methodology for exploiting the potential of using technology to improve logistical systems. The second contribution is the analytical framework and performance assessment model. The research presents an analytical framework based on four elements: logistics, technology, structure and procedure. This approach to analysing logistical systems within health care settings in order to identify the technology potential is new and adds to the body of knowledge on improving hospital logistics. A third contribution is disseminating the obtained results. The research produced three journal articles and three conference articles, all published in esteemed scientific communities.

Are the results reliable and valid?

In relation to the scientific contribution, it is important to investigate whether the presented results are reliable and valid. The third sub-question deals with the issue of making the framework reliable. As described by Cook and Campbell (1979), reliable results require that testing and retesting should be conducted and produce the same results. The issue of reliability is discussed in chapters 2 and 3. The approach is continuous testing of the framework on different cases in order to determine whether the framework and assessment model are comprehensible. The results of two cases were also compared to the results from a simulation model, thereby testing whether similar results would be obtained by using different analytical methodologies.

Trochim and Donnelly's (2006) thoughts on social threats to constructing validity are also considered in chapters 2 and 3. The threats have been acknowledged throughout the research and precautions taken in order to address them.

- The first threat relates to hypothesis guessing, which happens when participants think they know what the study is about, and the outcome from the interviews is based on the participants' reaction to the researcher and the study.

This threat has been dealt with by introducing precisely the logistical systems of interest in the research. In addition, as the analytical framework and the assessment model were developed, they were presented as needed in order to ensure a clear understanding of the research. In relation to the Japanese cases, however, the language barrier had to be taken into consideration. All questions had to be asked through a translator, which enhanced the risk of misunderstandings.

- The second threat was evaluator apprehension, which is when the participant is fearful of the study.

This is a very important issue, because part of the research aimed to automate the current systems. Therefore, the employees directly affected by the decisions may be inclined to withhold information that can threaten their jobs. This was dealt with by being aware of the situation of the personnel being interviewed and their interest in the research. Following the interviews, the answers were analysed in order to determine whether any kind of evaluator apprehension occurred.

- The third threat was experimental expectancies, which is when researcher reaction shapes the participants' responses.

Addressing this threat and that of hypothesis guessing can pose contradictions. The threat of experimental expectancies was dealt with by using an unstructured approach in the interviews. As a consequence, participants may not have a clear view of the context of the research. The context of the research was presented very thoroughly, however, which can lead to the risk of guiding the interviewee too much in a specific direction. In the Japanese cases, the interviews were conducted in a much more structured manner due to the language barrier, therefore risking experimental expectancies.

Applicability

The project was initiated mostly due to the practical need to construct an analytical framework that the hospital management could use. The challenges that Danish hospital managers must deal with in the coming years, both in terms of improving existing hospitals but also in relation to constructing new ones, create an incentive to use technology as a driver to improve hospital logistics. A need therefore exists for a framework like the one developed in this project. Precautions were made to ensure that, in principle, the framework is applicable to all hospitals. This was done by involving hospital personnel throughout all phases of the framework development to ensure that the framework matches hospital needs and can be used in the future.

Making the analysis and evaluation in relation to the four elements fits well with the approach taken by Danish hospitals in evaluating future technologies. It is becoming very important not only to justify technological changes by justifying the investment with a plan for a five-year return on investment, but also by increasing performance within specific areas. In relation to this specific issue, Herlev Hospital has already embraced the framework and implemented the methodology in their procedure for analysing logistical systems and evaluating different technological implementations.

Due to Herlev Hospital's heavy involvement in the process of developing and modifying the framework and the assessment tool, the hospital had confidence in them and was therefore much more inclined to implement the framework than would be the case if hospitals were less involved in the research and even less if hospitals were not involved at all. There can be no doubt, however, that the framework and the assessment tool can offer some value to the hospitals implementing them or the basic concepts.

In Danish hospitals, there is a tendency to try to take a more strategic approach to constructing and handling logistics. This requires that logistics are to a greater extent viewed holistically rather than departmentally. This research presents a holistic approach that considers the entire logistical system. This improves the potential for applying the framework to Danish hospitals that have not participated in the research.

Generalizability

In addition to investigating the applicability of the model, it is of interest to examine how general the research is and clarify the settings in which the research is valid as well as the settings that might pose some difficulties. The research was conducted within hospital logistics, more specifically hospitals' supporting flows. All the cases involved in developing and modifying the framework related to this type of flow. However, since the framework was developed in hospital settings where the requirements for the different types of flow, especially in terms of quality, were very similar, the framework could also have merit in relation to other flows. For example, the patient flow or the personnel flow might also be improved by using the framework to conduct an analysis of these systems. This would however require a new type of definition and delimitation of the patient flow or personnel flow being analysed. How should the delimitation of the patient flow be? For instance, should the delimitation be a patient with abdominal disease or a patient with a specific abdominal illness? Before applying the framework to any other flows, the boundaries of the flows must be strictly defined.

Another issue is the cultural context in which the framework was developed and tested. There is no doubt that the framework was primarily influenced by the Danish hospitals' participation in the research. Therefore, the research was tested in a Japanese setting. This test phase resulted in changing the framework so that it was applicable in both Japanese and Danish settings, which enhanced the general potential of the framework.

Although the framework was developed in a health care setting, the framework and assessment model address some of the same issues faced by production and some types of service organisations. The elements concept (logistics, technology, structure and procedure) could definitely be used to improve the logistical systems within some of these organisations. One aspect of the assessment tool is that the indicators are weighted according to their importance for the organisation, making it possible to construct an assessment tool that fits the organisation's concerns.

The framework presented in this research is a guide to making an analysis of the logistical system, and the assessment tool is used to measure its performance. However, the way the assessment tool indicators were created, with five attributes, makes it possible for any organisation to actually change the indicators to fit its needs. The framework and assessment tool can therefore be seen as a template for constructing an analytical framework, rather than a final analytical framework and assessment tool. Using the concepts presented in this research would therefore make it possible to customize an analytical tool originally designed for a specific organisation.

Practical impact

In relation to applicability, it is interesting to explore the research's practical impact. Which technological implementations were actually made due to the research? Have the framework and assessment model actually been implemented? Or will the work all be more or less forgotten after the research is finished? Are there other practical impacts generated by the research?

In terms of technological implementations, the research resulted in a pneumatic tube system being implemented at Herlev hospital to transport blood samples between the emergency department and the laboratory. The hospital is presently investigating whether it is possible to implement a robot to receive the blood samples when they arrive at the laboratory and place them on a conveyor belt connected to the automated analysis and testing equipment. Hvidovre Hospital is in the process of implementing five pneumatic tube systems to transport blood samples between the department and the laboratory as a result of the research. Finally, Herlev Hospital is in the process of testing different tracking technologies to be used to monitor and control the beds at the hospital. In addition, the hospital is investigating different washing equipment suppliers with the aim of constructing an automated bed washing machine.

As stated in the section on applicability, Herlev Hospital has embraced the framework and the assessment model and is implementing them in their procedure for investigating the potential of different technologies within logistical systems. This is especially important in relation to the expansion of the hospital and the different logistical systems being created as a result.

In connection with Herlev Hospital's future implementation and use of the framework, the hospital has allocated funds to a new PhD project to continue the research. The new PhD project has two major objectives: 1) to further develop and improve the analytical framework and the assessment model, and 2) to test the model on more cases with the aim of improving them.

5.3 Summary

This chapter presents a discussion of the project by investigating how the research design affected the results, and the impact of the methodologies and empirical foundation on the outcome related to each of the research questions. The research design consists of three sub-questions, all aiming to help address the research question. Initially, the research focused on establishing the theoretical foundation on which the research was to be conducted. This resulted in an approach where the effect of a logistical system was dependent on four elements – logistics, technology, structure and procedure. The approach was developed in close collaboration with Herlev Hospital. The degree of influence on the approach to the research of Herlev Hospital's views and ideas as to how to implement technologies in logistics is discussed. Because the theoretical foundation was primarily developed by the researchers and then presented to the hospital, the ideas contained some of those presented by Herlev Hospital, but also new thoughts they had not considered. The second part of the research focused on how to construct an analytical framework and assessment tool based on the theoretical foundation. The framework and tool were developed, tested and modified using eight different cases from four different hospitals (two Danish and two Japanese), thereby ensuring that the framework had a broad range of inputs. This also ensured that the framework was applicable to a wide variety of cases and hospitals and not only to the specific one it was designed for. As a result of testing and modification, the assessment tool was transformed into a quantitative model consisting of quantitative performance measures. Although this transformation was carried out during the external research stay in Japan, it is argued that the transformation would probably have been made even if a different empirical basis were used. In relation to this research question, a strict definition of hospital flows was constructed. The final part of the research addressed the issue of transforming the analytical framework into a reliable tool by developing the final framework and assessment tool. In addition, a thorough analysis was made by applying the framework to two different cases. The final framework included an additional aspect, an economic evaluation of the technological solution identified by the analysis. Finally, it is argued that the final framework is reliable based on using two different types of verification: one is to investigate the outcome of an implemented technological change proposed by the framework, also checking whether the expected outcome is in accordance with the actual outcome; the other is a simulation model constructed for two of the cases.

The results obtained in these cases are also in accordance with the results obtained from the framework.

Following the discussion of the research design, the research contribution is discussed. Initially, the discussion of the scientific discourse divided the contributions into three different areas: addressing and closing the gap, creating the analytical framework, and publishing the results. This was followed by a discussion of the reliability and validity of the results and the measures that had been taken in order to secure valid and reliable results.

The second aspect of the contribution focuses on the practical contribution by investigating the applicability of the results. It is found that the framework has proved its value to logistical systems, as it can be applied with great improvement potential. Next, the generalizability of the research is discussed. The framework definitely added value to the supporting logistical systems at the hospitals, and could probably also be applied to other hospital logistical systems. The framework also has potential for application to logistical systems within organisations outside health care. Finally, the practical impact of the research is discussed. A new PhD project is being initiated at Herlev Hospital in order to continue the research. The research results are implemented in the procedures at Herlev Hospital for using technology within existing and future logistical systems. Finally, based on the results from using the framework, three cases have implemented technologies or are in the process of investigating of technology suppliers.

Chapter 6 – Conclusion

In the following chapter the conclusions drawn throughout the project will be presented. The chapter will focus on both the scientific as well as the practical outcome from the research.

Making hospitals more efficient is a key point on the agenda in many developed countries. In Denmark, there is increasing focus on how the use of competences from other industries and sectors can help improve the way that health care institutions are managed. As a consequence, there is an increased awareness of the potential of using operation management ideas and tools to analyse different aspects of the health care sector. The current research project was initiated as a consequence of this awareness. Earlier, Danish hospitals have mostly been approached departmentally. As a result, logistics and other processes involving more than one department are sub-optimized within the departments, while the interactions between departments have not been optimized to the same level. Also, a lack of exploration of the full potential of using technology within logistical settings can be identified. Currently, the main use of technology is within clinical areas and in relation to improving surgery and patient treatment, and less in relation to improving non-clinical areas.

The research considered the logistics in a flow perspective, and as a result, four major hospital flows were identified: the patient flow, the personnel and resource flow, the information flow and the supporting flow. The most important is the patient flow; all the other flows are in place to make the patient flow function. The supporting flow relates to all goods and items used in the patient flow. In this research, it was decided to develop a tool to analyse and improve the supporting flow.

The research presents an approach that analyses hospital logistical systems and assesses technological implementations that can improve the system and the extent to which the system will be improved. The approach is based on the principle that there is a relation between the effect of a system and four elements: logistics, technology, structure and procedure. The approach consists of two main parts: an analytical framework and a performance assessment tool. The analytical framework is an eleven-step method used to conduct a holistic analysis and evaluate the logistical system.

The analytical framework consists of three parts. The first part includes steps 1 through 7 and deals with defining and analysing the current setup. These seven steps measure the performance of the system and identify poor performance within the system. Steps 8 through 10 deal with idea generation in relation to improving the current setup. Here, different technological solutions are identified, and the effect of implementing each of them is estimated. Step 11 explores the possibility to implement the ideas and the financial aspects involved in implementation.

The performance assessment tool functions as a means to measure the performance of the logistical system analysed using the framework. Performance is measured on the basis of fourteen different indicators categorized according to the four areas (logistics, technology, structure and procedure) on a continuous scale from 0 to 1 for each of the indicators. This ensures that the indicators can be aggregated, and that performance on an overall level and within each of the elements can be determined.

Using a rigorous process of testing, retesting, verifying, and modifying the results from eight cases in four hospitals ensures that the framework has been developed using a scientifically valid approach. This has further ensured that the framework is applicable to many different hospitals and cases and not just one.

The analytical framework has had practical impact and generated actual changes. A pneumatic tube system has been implemented at Herlev Hospital to transport blood samples between the emergency department and the laboratory. Furthermore, the hospital is investigating the possibility of implementing a robot to receive blood samples when they arrive at the laboratory. In addition, the hospital is in the process of testing different tracking technologies to be used to monitor and control hospital beds and investigating different washing equipment suppliers regarding construction of an automated bed washing machine. Finally, as a result of the research, Hvidovre Hospital is in the process of implementing five pneumatic tube systems to transport blood samples between the wards and the laboratory.

The research project was initiated to solve a practical problem, and the results show that it is possible to develop a scientific model capable of solving such problems. Due to the emergent need for making hospitals more efficient, scientifically developed tools can play a very important role in aiding hospital decision makers in their continuing efforts to improve their hospitals. The developed model is the first step in the process of addressing the potential of using technology to improve hospital logistics. It can therefore be concluded that the work generated in this research has contributed to the body of knowledge on hospital logistics.

Chapter 7 – Future research

This research study has been developed over a period of three years, which prescribes some limitations regarding the scope and boundaries of the research. In the course of the research, however, some interesting aspects materialized that would be very interesting to investigate further. In this final chapter, some of the ideas for further research are presented.

7.1 Indicator correlation

The main outcome from this research is the performance assessment tool. The indicators form the foundation of the framework, and are therefore of great interest in order to make the research more reliable. One issue concerning indicators is how they are related to one another. If a correlation exists between the indicators, then a given aspect of a logistical system or technology can be over-represented, thereby making the indicators perform more positively or negatively than is actually the case. Another problem arises if the indicators are negatively correlated, so that implementing technology to improve performance for one indicator results in poorer performance for another indicator. It could therefore be of great interest to investigate if there is some correlation between the different indicators and how they are correlated. With a thorough overview of indicator correlation, it would be possible to construct a more trustworthy performance assessment model, and obtain an even better analysis of the consequences of implementing new technologies.

7.2 Using structure and procedure as the basis for changes

The foundation for the research is that a relationship exists between the efficiency of a logistical system and logistics, technology, structure and procedure. Based on this foundation, the analytical framework and performance assessment tool were developed. In the research, the framework and tool were applied to a number of cases with the aim of improving performance. The approach used and the basis for making improvements related to changes in technology and logistics. However, there might also be great potential in making changes in structure and procedures. It would therefore be of interest to investigate how to use structure and procedure as the basis for making changes. This would provide hospital management with more opportunities when they investigate how to improve the logistical system, instead of only using technology or logistics. The performance assessment framework measures performance for these four elements. If structure and procedure formed the basis for changes/improvements to the system, it would be possible to make changes that are more directly related to the causes of the poor performance when such performance is not related to technology and logistics. This added dimension to the analytical framework would give an added dimension to the continuous improvement of the system. The initial changes to the system could be a technology implementation, and when this technology is implemented, it would then possible to analyse the system again and assess other improvement potentials in addition to technology.

7.3 Economic assessment

The analytical framework is constructed so that the logistical system is analysed and a recommendation regarding the potential for implementing new technologies is presented. For hospital managers, however, an additional step is extremely important – ensuring that the technological implementation is financially viable. The last step of the analytical framework is therefore to conduct an economic assessment of the technological implementation. Currently, the approach used for the economic assessment is to estimate the investment cost for the technological implementation and the savings obtained from the implementation. It can cause some concern for the hospital management if the estimate of the economic consequences is not as thoroughly investigated as the investigation of the performance of the logistical system. Therefore, it could be of great interest to investigate in depth how an economic assessment should be conducted and, for instance, gain better understanding of what are perceived as obtainable savings, both in terms of direct savings and indirect savings, and how to estimate them.

In some situations, hospitals decide whether to make investments based on business cases. In these situations, the analytical framework does not need to make an economic assessment, but can present the obtainable improvements from technology implementations, adding the recommendation based on the business case as to whether or not to carry out the implementation.

7.4 Testing further cases

The analytical framework is solely developed and tested for supporting flows in hospitals. However, as explained in Chapter 5, the framework may also be applicable to other types of logistical systems – also outside the health care sector. It could therefore be of interest to test the framework on different types of cases in order to investigate applicability. If the applicability of the framework were enlarged to also include other types of logistical systems, the hospital would then have a tool that could be used to assess all different types of logistical processes in order to improve hospital efficiency.

7.5 Summary

During this research project, a number of interesting issues arose which unfortunately could not be investigated further due to the scope of the project. Bit it could be of interest to investigate the construction of the performance assessment tool, and especially the indicators, further. The indicators may be correlated, and it would therefore be of great interest to investigate to which extent this is the case in order to construct a tool that gives a better picture of the effect of implementing technologies. Although the focus of the research is on how technology can be used as the driver to improve logistical systems, the performance of the system is also measured within structure and procedure. It would therefore be of interest to examine further how these two areas can be used as the driver for change and performance improvement. Another area of interest is the economic assessment of the technological implementations. Currently, the step in the analytical framework describing the economic assessment gives only a vague idea of how the assessment should be conducted. Exploring how to conduct the economic analysis of the implementation would improve the analytical framework. Finally, it would be interesting to test the analytical framework on other logistical systems than the supporting flows, and thereby expand the applicability of the framework.

Chapter 8 – Literature

All references used in this thesis will be presented in the following chapter in alphabetical order using the family name of the first author. Three different types of references have been used, Books, Articles and Webpages. Harvard – British referencing style is used, and the detail sequence is Author, Year, Publication name, Journal name and details on volume number.

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Chapter 9 – Appended Papers

The six full papers which this thesis is built upon are appended in this section of the thesis. Three papers are conference proceedings which both have been presented and published as part of international conferences. Three papers have been submitted to international recognized journals, one is published, and two is still undergoing 1st review phase after submission. Full publication details are provided for each paper.

Paper 1

P1: Improving Hospital Logistics by Rethinking Technology Assessment

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IMPROVING HOSPITAL LOGISTICS BY RETHINKING TECHNOLOGY ASSESSMENT

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ABSTRACT

In order to cope with the future challenges of the health care sector, there is an urging need for improving efficiency at hospitals. The study presents a framework enabling health care managers of improving the in-house logistics. The distinctiveness of the framework is the way in which it relates technology, logistics, structure and procedures to efficiency. Changing one factor e.g. technology, initiates an iterative loop focusing on change in the related factors in order to obtain the optimal efficiency. The search for an optimal efficient solution is the driving force of the framework, and will secure one iterative circle followed by another in an endless journey. The framework represents innovation as a broad solution where iteration between important factors secures an optimal solution. The study is performed as a case study with close relations to the staff at an emergency department at a Danish hospital. The framework is tested on the blood sample logistics between the emergency department and laboratory with the goal of enhancing the efficiency of the emergency department.

Keywords: Health care, logistics, technology assessment

1. INTRODUCTION

The developed countries will face a situation where the ratio of people needing care and the people providing health care will change dramatically (OECD 2007). Additionally modern healthcare is characterized by increasing demands for individualized high quality services, and rapid development of health care technologies, all resulting in increased pressure on in-house logistics. At the same time managing in-house logistics is becoming exceedingly complex as health institutions evolve into integrated health systems comprised of hospitals, outpatient clinics and surgery centers, nursing homes, and home health services (Curtright, Stolp-Smith 2000). Hence there is an increasing demand for utilizing the technological possibilities in order to optimize the logistical systems, and thereby maintaining the same health service level with less medical personnel.

Innovation and development of new technology in health care has mainly been related to the clinical area. Less emphasis has been on the use of technology to solve the emergent logistical challenges. Solving in-house logistical challenges has primarily been approached with a departmental (horizontal) view, and thereby lacking the holistic view of the entire in-house logistical system (vertical) leading to sub-optimization of the logistical system (Mayfield 2009, Shumaker 2007, Banerjee, Mbamalu & Hinchley 2008).

Implementation of new technology often results in modification of operational activities resulting in a change of procedures, as well as it often results in changes in the organizational structure. Consequently there is a need for developing a holistic framework that is capable of tying the different disciplines together and identifying the effect of implementation of a technological and logistical system at hospitals. Therefore establishing a framework that shows a clear and transparent link between logistics, technology, efficiency, procedure, and structure will be a new and innovative approach to dealing with implementation of technology in health care settings.

The paper will present a framework based on the presented considerations applied to a specific case, in order to test and validate the framework.

2. THEORETICAL BACKGROUND

In order to understand how to think logistics and technology in health care, it is necessary to define the terms. Britannica Online Encyclopedia defines logistics as "...the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements." The definition of technology is "…the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment." Using these two definitions to achieve higher efficiency and service can then be looked as a change in the flow of goods, services, and related information by using products and services created by the application of scientific knowledge. If the use of Operations Management and LEAN thinking is brought into this context, it is the scope to create a systematic approach at improving the logistical systems by using new technological possibilities.

Literature concerning health care seems to be concentrated on sub optimized solutions, and the main focus is within three major areas. The first major area is concerned with new technological methods to improve patient treatment and diagnosing. This part of the literature is mainly focused on the new technological possibilities and inventions made, based on clinical results from various cases (Stein 2009, Nejat, Sun & Nies 2009, Spear 2005, Barbash, Glied 2010, Mendez et al. 2005, Berlinger 2006, Carlsson et al. 2010, Brennan, Mawson & Brownsell 2009, Okamura, Matarić & Christensen 2010). The second area of the literature focuses on telemedicine and the possibilities that this technology gives. Telemedicine is gaining increasing focus with journals entirely dedicated to this area e.g. *Journal of Telemedicine and Telecare*, *Telemedicine and e-Health*. The literature within telemedicine is primarily concerned with the possibility of treating and monitoring patients at home instead of at the hospital (Brennan, Mawson & Brownsell 2009, Lanseng, Andreassen 2007, Menachemi, Burke & Ayers 2004, Chau, Hu 2004), as well as the possibility of doctors being physically located at one hospital but using technology to do surgery and other treatment at another hospital (Mendez et al. 2005, Berlinger 2006, Brennan, Mawson & Brownsell 2009, Okamura, Matarić & Christensen 2010, Chau, Hu 2004, Xiao et al. 2010, Gagnon et al. 2003). The third major area of technology literature in healthcare is within ICT (Information and Communication Technology). The primary focus is how to digitalize and control patient data (Lanseng, Andreassen 2007, Xiao et al. 2010, Neumann, Blouin 1999, Thompson, Dean 2009, Devaraj, Kohli 2000, Herriott 1999, Bogner 2010). Other areas with less focus in the technology literature are technology assessment (Neumann, Blouin 1999, Johnson et al. 2009, Thielst 2007), ethical issues concerning the use of robots in health care (Coeckelbergh 2010, Sharkey 2008), and the use of robots and other technologies used for rehabilitation of patients (Stein 2009, Nejat, Sun & Nies 2009, Okamura, Matarić & Christensen 2010, Matarić et al. 2007).

Exploring the literature focusing on logistics in the health care sector four major areas has had great attention. LEAN in health care has had a lot of attention within the last couple of years (Banerjee, Mbamalu & Hinchley 2008, Spear 2005, King, Ben-Tovim & Bassham 2006, Dickson et al. 2009). The literature has been divided into case study works or more theoretical founded publications (Souza 2009). Secondly the use of RFID and other logistical tracking devices has been used in health care. The focus has been on how to improve logistics by having tracking devices to control the logistics very closely, with the aim of improving patient safety (Pan, Pokharel 2007, Florentino et al. 2008, Awami, Swatman & Calabretto 2009). A third area with great interest is the flow of patients (Vermeulen et al. 2009, Vissers, Beech 2005) and structure of departments (Oddoye et al. 2009, Espinosa, Case & Kosnik 2004, Norrish, Rundall 2001, Villa, Barbieri & Lega 2009). This literature is concerned with how to make a better patient flow at hospitals. The last main area focuses on the supply chain of hospitals with emphasis on external logistics and the purchasing function at hospitals (Pan, Pokharel 2007, Jarrett 2006, Poulin 2003, Sinha, Kohnke 2009, King 2004, Birk 2008, Dooley 2009, Lapierre, Ruiz 2007, Vries, Huijsman 2011).

The aim of this project will therefore be to focus on a broad and holistic view of the flows in a health care area and analyze how a combined technological and logistical solution can improve the efficiency. The project includes a framework that relates efficiency to technology, logistics, structure and procedures. Using a structured framework in this sense will secure that flow costs are systematically lowered which is one of the criteria for "innovative care-process change" according to Paulus, Davis & Steele (2008). As the search for better efficiency is a continuous process the framework will represent a never ending journey. This never ending journey is related to continuous improvement and innovation as it can be difficult to separate these two terms from each other as defined by Chapman & Corso (2005) "…as both the small-step continual improvement activities are necessary, as well as the more dramatic, on-going technological-, organizational- and market-based changes normally considered under the term innovation".

3. Research question

In order to address the problems and challenges the health care sector is facing, the following research question has been formulated, "How can technology improve the logistics and service in the health care sector?" Four sub-questions are constructed to support the research question. The two first sub-questions relate technology to logistics.

1. Which relations exist between technology, logistic, efficiency, procedure, and structure?

2. How can a model be created containing technology, logistic, efficiency, procedure, and structure?

The last two sub-questions relates to practice.

3. How can a hospital use this model?
4. How can new technology concepts be included in the different existing logistical flows?

4. METHODOLOGY

Based on the research question and sub-questions the study has been performed as a case study (Morgan, Morgan 2009, Voss, Tsikriktsis & Frohlich 2002), with close relations to the staff at the Emergency Department and the laboratory at a Danish hospital. Case research is good for exploring certain phenomenon within “some real life context” (Yin 1991). This makes case research suitable in regard to this study due to the focus on building and testing a conceptual framework.

The study consists of two main processes; creating the framework and testing the framework. The two phases are closely combined because the framework will be adjusted according to the experience gained from the testing. This makes the present study follow an iterative process where the theoretical development of the framework is supplied with case study.

The creation of the framework started with a deductive process establishing the theoretical foundation using literature survey followed by an inductive process using semi-structured interviews (Winter, Munn-Giddings 2001) and on-site observations (Maaloe 2002). The literature survey focused on the literature concerning health care, logistics, and technology. The interviews were conducted with staff members from both the emergency department and the laboratory. The aim of the development process was to create the framework so that it was capable of analyzing the logistical systems followed by an analysis and evaluation of the effect of implementation of different technological possibilities.

The second part of the study was an empirical exemplification; analyzing the blood sample logistics from the emergency department to the laboratory and result back to the emergency department. The hospital had a great interest in using this case and it was an obvious case for the research project. The hospital is in a situation with increased pressure on the emergency department. This is a result of the Danish Health Care Reform (Andersen, Jensen 2010), which have resulted in the intake of patients at the emergency department increasing 15 % from 1st of January 2011, without the department getting any additional funding to cope with this increase in patients. This constitutes a need for making the emergency department more efficient. One approach is to diagnose the patients faster, in which blood testing plays a crucial part. Making the blood sample logistics more efficient will enable the emergency department to be more efficient. Having the hospitals interest in analyzing the system makes it easier to get access to data and employees.

All the interviews were conducted in a semi-structured and informal manner, with the emphasis on the interviewees telling their “story”. The questions posed to the interviewees were in relation to quality and traceability issues, and what are the criteria for a successful logistical system in relation to their tasks and working routines. Prior to doing the interviews it was emphasized by fellow health care researchers, that personnel at public hospitals often have a negative attitude towards the way things are currently running as well as to doing changes. This paradox was kept in mind during the interviews as well as when the interviews were being "decoded".

The goal of the interviews was to establish a perspective on how different health care employee groups consider technology implementations, and the main concerns in regard to their field of work. Both nurses and doctors were interviewed in the emergency department followed by on-site observations in the emergency department. This gave an insight to the requirements at a department with a particular stressful environment. Interviews were also conducted with doctors and biomedical laboratory technicians working in the laboratory at the hospital. This gave an insight to the concerns of personnel were the clinical quality is of utmost importance. Lastly administrative personnel within the department of Internal Service and Logistics were interviewed, who mainly has an efficiency and economic perspective on the logistics.

Further interviews with laboratory personnel and on-site observations have been conducted at a similar laboratory at another Danish hospital. This hospital has experiences from implementing new technology in a comparable logistical system, using the case as a further evaluation and validation of the constructed framework. The total amount of interviewed employees was 20 people.

The basis of the analysis conducted using the framework was based on different static analyses. A functional analysis using $IDEF_0$ (Ang, Gay Robert & Khoo 1999), value stream analysis, competence shifts were highlighted using process map (Bicheno, Holweg 2008), 5S analysis to eliminating waste and possibilities for standardization (Russell, Taylor 2009), finished off with Poka Yoke (Bicheno, Holweg 2008) for error prevention and traceability. This was followed by a dynamic analysis using simulation. The simulation is excellent in testing real life logistical problems in a controlled manner, and is therefore a good way of evaluating different logistical systems, as well as pointing to problems within the analyzed system (Karlsson 2009). These analyses ensure that a full picture of the current system of the potential improvement is gained.
All additional data used have been extracted from databases at the hospital.

4.1 THE CASE

The case represents the situation where a blood test is taken at an emergency department, transported to a laboratory, tested and finally the result is send back to the emergency department. Two Danish hospitals have been involved as cases. The primary case is a Danish hospital having the responsibility for the health services of approximately 425.000 inhabitants. The secondary case is a Danish hospital with the responsibility for the health services of approximately 300.000 inhabitants.

4.2 FRAMEWORK

The framework consists of two triangles merged together, see figure 1. Each triangle represents a separate iteration. The first triangle represents logistics, technology and efficiency. The three areas affect each other in an iterative manner. The second triangle represents structure, procedures and efficiency, also here the three areas affects each other. By merging the two triangles a relationship between logistics, technology, organizations and procedures is obtained with efficiency as a resulting parameter.

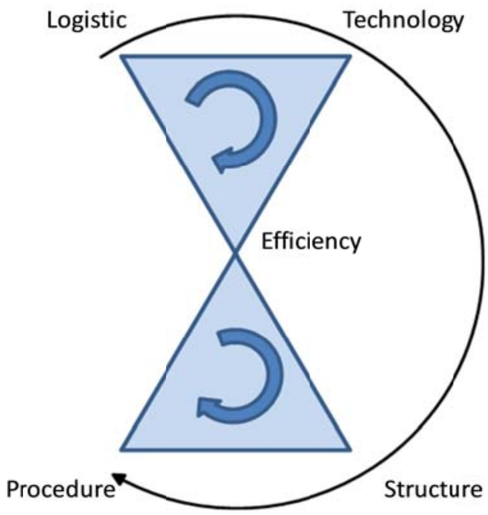

Figure 1. The framework

The logistic in our framework is mainly controlled by, 1) the distance between start and end point, 2) the quantity moved between the points, 3) the frequency the quantity has to be moved and 4) the speed the quantity is moving.

The technology is mainly controlled by 1) the method or principle used and 2) the medium or tool transferring the technology.

The structure represents the relation between the following, 1) the division, 2) the hierarchy, 3) the organization and 4) present competences.

The procedure expresses the approach for doing certain actions and processes and is expressed by 1) what is the process, 2) who does it and 3) the sequence of the processes. The procedures can both represent physical actions and the information flow related to another flow e.g. a patient flow. The procedure will be inspired by the LEAN philosophy.

Changes in efficiency can be measured and evaluated in many different ways, all depending on the logistical system. Criteria and parameters can for instance be lead time, number of handover situations, length of stay (LOS), resource utilization etc.

Health care is a constantly changing environment with constantly changing demands. Therefore the framework needs to be constructed in order to cope with this ever changing environment.

4.3 APPLYING THE FRAMEWORK

By applying the framework to the case the following procedure was used;

1. The system is chosen and bounded.
2. The system is described and the overall processes defined.
3. Quality demands and specification requirements are defined.
4. Technological possibilities for each of the overall processes are explored through study of the literature, searching the internet, and through brainstorm with employees.
5. The system at the hospital of analysis is thoroughly described using e.g. $IDEF_0$.

6. The processes, where responsibility is shifted from one department to another, are thoroughly analyzed.
7. A flow chart is created showing the linkage to the overall processes.
8. The structure and related procedures are analyzed and described.
9. Using the flow chart combined with VSM, 5S, and Poka Yoke.
10. The analysis gives a basis for recommendation for improvements.

Using the specific case of blood testing, the logistical system can on an overall level be divided into four major processes, and the different technological possibilities within each of the processes;

- Taking the blood sample
    - Manually
    - Automatic
- Transporting the blood sample to the laboratory
    - Manual transport
    - AGV
    - Pneumatic tube system
    - De-central laboratories
- Testing the blood sample
    - Manually
    - Automatic
- Transporting the result of the test back to the emergency department.
    - Physical
        - Manually, AGV, pneumatic tube
    - Electronic
        - Computer, fax, telephone

The important quality criteria for the system were defined as;

- Violence to the blood sample during transportation
- Time between blood taking and blood analysis
- Influence of temperature
- Traceability
- Number of handover situations

The analysis and description of the current system developed into a flowchart presented in figure 2.

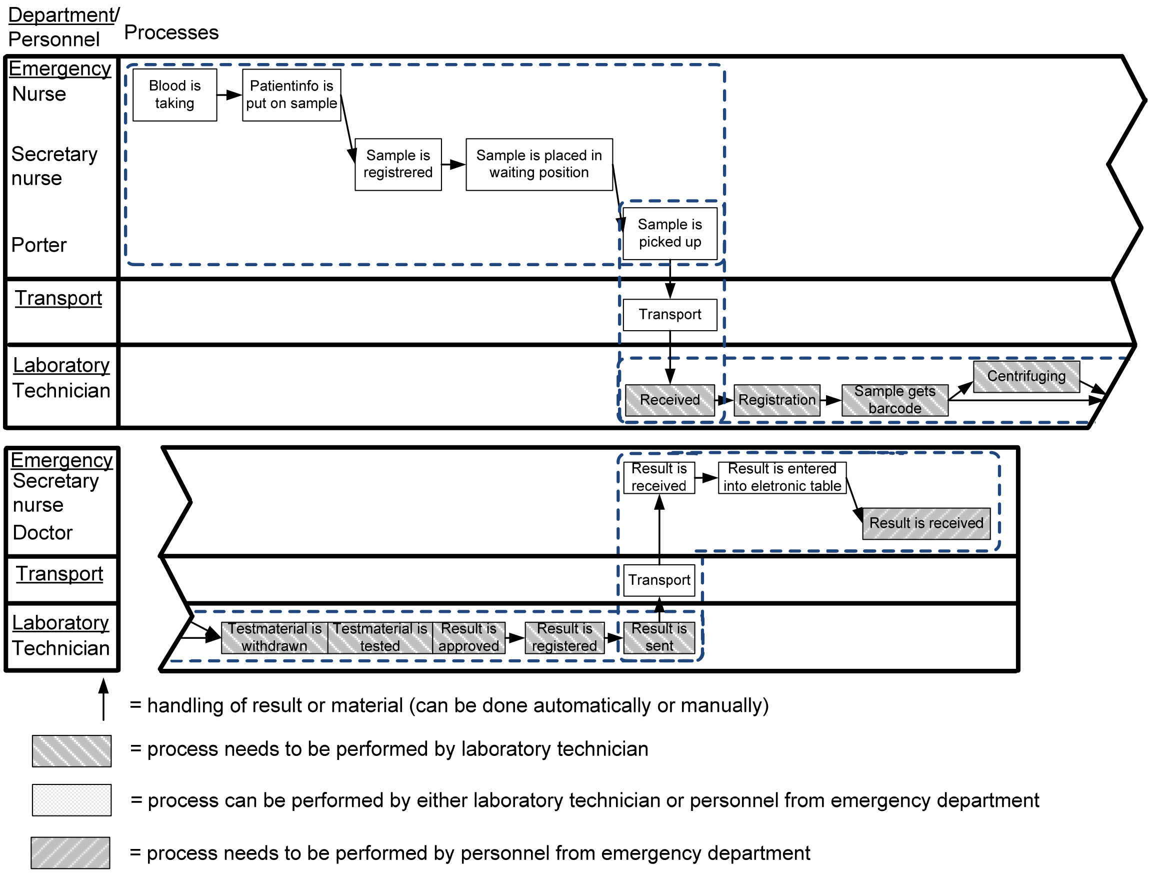

Figure 2. Flow chart of the analyzed case

Figure 2 shows the flow chart for the analyzed case. The flow chart shows where and by whom the processes are done. The flow chart is divided into two parts in order to make the figure manageable.

5. RESULTS

Using the quality criteria and the analysis of the system, considerations in regard to the overall level and recommendations for each of the major processes can be presented.

Overall level:

- A lot of non-value adding time in the transportation
- The feedback of the result was functioning very unsatisfying
- An unnecessary high number of competence shift where a handover situations takes place
- Some processes were being conducted unnecessarily

Blood taking process:

- The nurses should register the blood samples instead of the secretary. This can be done by having a barcode equivalent to the patient on the blood samples that the nurses can scan after the blood samples are taken.

Transportation of the blood sample:

- Locating the laboratory and the emergency department close to each other would be the optimal, but an extremely expensive and not realistic solution. The best technological solution is therefore a pneumatic tube system, which has its beginning at the emergency department and end at the laboratory.

  - The pneumatic tube system works at other hospitals.
  - The quality of the blood samples is maintained.
  - This system will decrease the transportation time by up to 40 minutes.
  - The investment will be saved within two years. The system cost app. € 67.000 to install. Two transporting porter positions each with a salary of app. € 27.000 per year will be saved.

Analysis of the blood sample at the laboratory:

- The analysis is highly automated but attention to the hand-over situations receiving the blood samples should be taken.

Transportation of result back to emergency department:

- When the result is received in the emergency department, the personnel responsible for the patient should be notified immediately, instead of having to look for the answer themselves. One solution would be by giving the doctors some form of PDA or notifying them via their telephone. The device should then be linked to the system in the emergency department controlling the patients, so the doctor will be notified when the result is available for his/her patient, as well as being notified if it is a critical result. Another solution could be big screens in the emergency department that show some kind of alarm when a result is ready.

Besides these recommendations, it is extremely important that the implementations are done so that focus is on the handover in between department. This is especially important due to the risk of sub-optimizing the system. If the different processes are optimized but the linkage between the processes is neglected, this will result in the problem of not getting the optimal out of the system.

5.1 *RECOMMENDATIONS*

Using the results founded in the analysis of the system combined with the results from the simulation the biggest improvement to the system would be achieved by changing the transportation process into a pneumatic tube system. Implementing the pneumatic tube system resulted in a number of changes and considerations to the current setup.

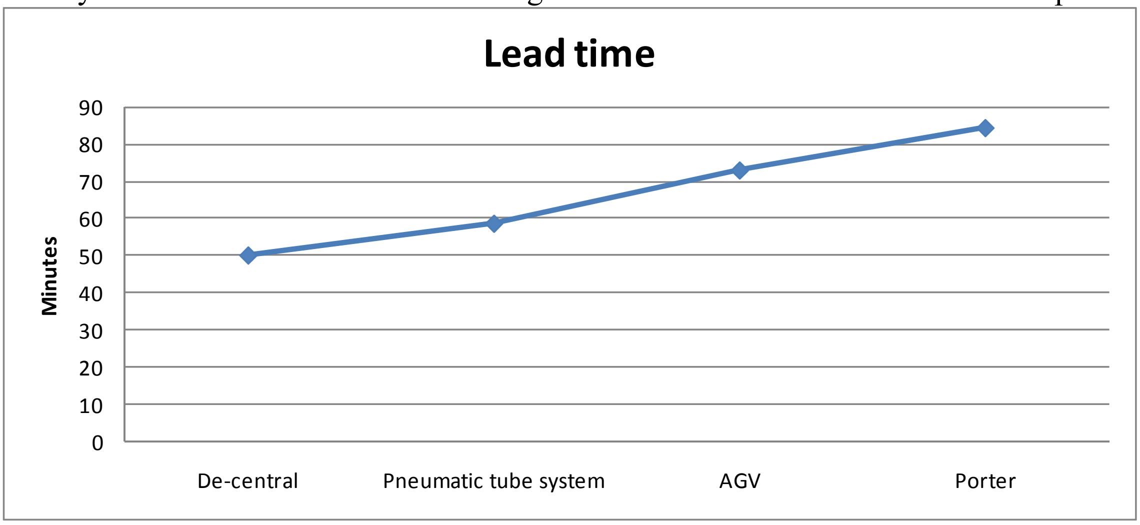

Figure 3. Lead time using different transportation technologies (Burasci, Demelas 2011, Nandrup-Bus 2011)

- The change in efficiency:
  - The simulation shows that the lead time of the blood samples will be reduced from app. 74 min. to app. 51 min as shown on figure 3. This change will have a big impact on the flow of patients in the emergency department.
  - The amount of handover situations will also be decreased from 5 to 3. This minimizes the risks for errors.
  - The length of stay (LOS) of the patients will be able to be reduced with the same amount as the lead time app. 23 min.
- Technology change:
  - The technology will be changed from a purely manual approach into using a pneumatic tube system. It will be a more reliable system with low maintenance costs
- Logistics:
  - The implementation will change the value stream of the system eliminating unnecessary activities.
  - The tests will arrive at the lab more smoothly avoiding the risk of having queues.
- Structure of the system:
  - On a short term the change will result in two positions being cut back, because there will not be a need for the blood sample porters after the implementation.
  - On long term the system will probably have some effect on the personnel in the emergency department, because the system will be more effective and therefore there might be need for fewer personnel.
- Procedure:
  - Instead of the secretary the nurses will have the responsibility of registering the blood samples before sending them. The nurses will also have the responsibility of informing the laboratory that the blood samples have been sent and arrive shortly after at the laboratory. The notification will probably be done by pressing a button.
  - At the laboratory the personnel needs to be aware that samples from the emergency department will arrive continuously compared to every half hour currently.

6. DISCUSSION

The overall aim of the study was to examine how efficiency can be improved by technology and logistics. In order to fulfill this aim, four different sub-questions were presented. Two of the questions focused on the theoretical part of creating the framework and the second two were related to the usage of such a framework.

The theoretical part of the study focused on developing a framework capable of doing an analysis of a logistical system at a hospital and show relations between technology, logistic, efficiency, procedure, and structure. This has been done to a certain extent. The framework was based on a literature survey that is general for all logistical systems at hospitals. The purpose of the framework was to secure solutions based on a broader basis and in this way avoid sub optimization. Additionally the framework should secure a continuous process. The framework was then tested, refined, and validated using a single case study. This constitutes some concerns about the applicability of the framework in relation to other logistical systems.

In terms of the second part of the study the framework were tested on a specific case at a hospital. The framework fitted nicely with the specific case, the logistical system was fully analyzed and recommendations as to where the biggest improvement will be reached were presented. In this sense the study showed how to apply the framework, and how new technology can be included in the existing logistical flow. Further the effects achieved from the implementation were examined, and the management at the hospital has decided to implement the pneumatic tube system at the hospital.

7. CONCLUSION

The contribution of this study is a descriptive analysis within innovation research (Crossan, Apaydin 2010, Boer, Gertsen 2003). There are two innovative aspects of the research. Firstly the approach of developing a framework for analyzing logistical systems and exploring how this system can be improved by implementing new technology, and how the systems should be change in terms of procedure and structure to get the full potential out of the implementation. Secondly the way the framework has been constructed secures the possibility to continuously evaluate a logistical system, pointing out what technological implementations have the largest beneficial effect.

Crossan and Apaydin (2010) use the definition of radical innovation as “fundamental changes and a clear departure from existing practices in the organization” whereas incremental innovation is seen as a “variation in existing routines and practices”. In this context the framework is considered as a an approach to do incremental innovation to the logistical system, due to the approach in which the framework not only focuses on the technology, logistics, and efficiency but also what impact this will have concerning structure and procedure.

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Paper 2

P2: Assessing Technology in Hospital Logistical Settings: Comparing Danish and Japanese Health Care

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ASSESSING TECHNOLOGY IN HOSPITAL LOGISTICAL SETTINGS: COMPARING DANISH AND JAPANESE HEALTHCARE

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ABSTRACT

In order to cope with the future challenges of health care sectors all around the world, there is a need for monitoring and improving efficiency at the hospitals. This study presents a framework capable of measuring the performance of supporting logistical flows at hospitals as well as assessing the potential of implementing new technology. The framework has been constructed as a holistic tool both addressing the performance of the overall flow as well as that of the individual processes.

The framework has been developed and tested in both Denmark and Japan securing that the framework is applicable to health care institutions with very different backgrounds. Additionally the differences in-between the Danish and Japanese health care system have been identified as part of the process of developing and testing the framework. The study showed that there are big differences in-between the health care systems, which has a large affect the use of technology.

Keywords: Cultural differences, health care, logistics, technology assessment.

1. INTRODUCTION

As the first round of baby boomers turned 65 years old in 2011, the developed countries will face a situation where the ratio of people needing care and the people providing healthcare will change dramatically (OECD 2007). Concurrently the financial crisis have resulted in increased focus on the budgets of healthcare institutions, with the aim of cutting down on expenditures. Accordingly modern healthcare is characterized by increasing demands for individualized high quality services, and rapid development of healthcare technologies, all resulting in increased pressure on in-house logistics. Hence there is an increasing demand for utilizing the technological possibilities in order to optimize the logistical systems, and thereby maintaining the same health service level with less medical personnel at a lower cost.

The use of innovation in relation to new technology in healthcare has mainly been within the clinical area. Less emphasis has been on how to solve the emergent logistical challenges by using technology. Additionally solving the in-house logistical challenges has primarily been approached with a departmental (horizontal) view, and thereby lacking the holistic view of the entire in-house logistical system (vertical) leading to sub-optimization of the logistical system (Mayfield 2009, Shumaker 2007).

Consequently there is a need for a holistic tool capable of analyzing the logistics at hospitals, in order to pinpoint poor performance in the current setup. Additionally there is a need for a tool with the capability of assessing the impact of technological implementations in the logistics. As a consequence a framework has previously been developed to cope with this need (Jørgensen, Jacobsen 2011).

The framework consists of four different parameters; the specific logistical process, the technology used in performing the logistical process, the structure supporting the logistical process (referring to the personnel resources), and the procedures describing how the process is performed. Each of the parameters consists of indicators used to assess the performance of the parameters. The framework has been developed, tested and modified using four Danish cases.

The aim of this study is to test and further develop the model in a completely different context, but in a health care sector that has similarities with the Danish. Japan has been chosen because it is a developed country with a well functioning health care sector. There are however also very big differences between the two countries. The culture in-between the two countries is very different, but also the perception and approach to new technology and innovation is very different. Using Japan as the case for testing and modifying the model will have two important outcomes; get an insight into how the Japanese healthcare sector approaches the use of new technology in logistics, and test whether the framework is applicable in its current state to a Japanese setting. In terms of exploring new technology Japan is especially interesting because of the extensive use technology in everyday life.

Testing the framework in a Japanese context will improve the framework and the analysis and results obtained from implementing the framework.

2. Theoretical Background

Health care is an area with a lot of focus, and as a result it is very heavily researched. Exploring the research performed within innovation and technology in health care shows that the focus has been on how to enhance the quality of treatment (Paulus, Davis & Steele 2008), treating patients at home (Coughlin, Pope & Leedle 2006), making better diagnosing of illnesses (Okamura, Matarić & Christensen 2010), as well as technology assessment and innovation in health settings (Plumb et al. 2010).

Exploring the literature regarding logistics in healthcare shows a focus on the use of LEAN in healthcare (Souza 2009), using devices to track the logistical flows (Pan, Pokharel 2007), how to construct hospitals to improve logistics (Villa, Barbieri & Lega 2009), as well as the possibilities of improving procurement at hospitals by using ICT (Dooley 2009).

The present study focuses on exploring the combination between logistical analyses and assessing the potential of new technology. The study further addresses the differences in dealing with the implementation of new technology across two different countries which have very different cultures. This way the research combines elements from LEAN and technology assessment literature.

The logistics in focus in this research is that of the supporting flow at hospitals. At hospitals there are four major flows (figure 1). There is the patient flow, the personnel- and resource flow, the information flow and the supporting flow. The most important flow is the patient flow, and all the other flows are put in place to make the patient flow function. The supporting flow referred to that of all goods and items used in the patient flow. An example of this is the blood samples taken in the emergency department. The patient gets his/her blood taken, the blood sample is transported to the laboratory for testing, and the result is sent back to the doctor for diagnosing the patient (figure 1).

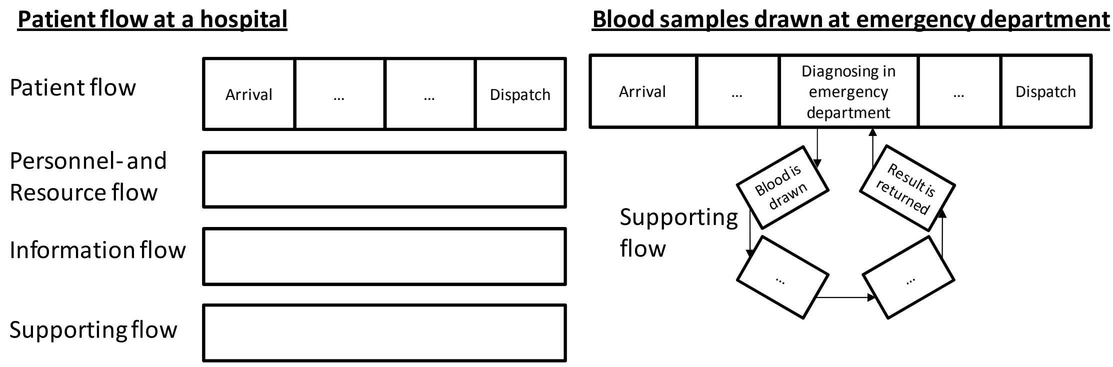


Figure 1. Flows at a Hospital and Example of supporting Flow

3. RESEARCH OBJECTIVE

This study has two aims. The first one is to test whether a framework developed in a Danish setting will be applicable to a Japanese context. The framework was constructed based on four parameters, i.e., the logistic, technology, structure and procedure, and it specifies the relation between these four parameters and the efficiency of a logistical system.

Additionally it is the aim of the study to explore the use of technology in the supporting flow logistics at Japanese hospitals. This would help identify the drivers for implementing technology in Japanese health care, and thereby improve the framework.

4. METHODOLOGY

The research has been performed as a case study (Morgan, Morgan 2009, Voss, Tsikriktsis & Frohlich 2002) with close collaboration to the staff responsible for different in-house logistics at four Japanese hospitals. Case research is an effective approach for exploring certain phenomenon within “some real life context” (Yin 1991), which makes case research suitable in regard to this study, due to the focus on testing the framework in a new context as well as getting an insight into the Japanese health care system. This case study has been performed by conducting semi-structured interviews with the personnel (Winter, Munn-Giddings 2001) and on-site observations (Maaloe 2002).

The framework was tested and modified on four different cases.

- Logistics of blood samples taken on walk-in patients. Blood samples are taken, samples are transported to the laboratory, samples are analyzed and result is sent to outpatient clinic.
- Logistics of blood samples taken on the wards. Blood samples are taken, samples are transported to the laboratory, samples are analyzed and result is sent back to the wards.
- The logistics related to hospital beds. New linen is put on bed, bed is used by patient, linen is taken of bed, linen is sent to cleaning, and clean linen comes to the department.
- Logistics of surgery tools. Tools used in operation theatres, tools transported to cleaning, tools are cleaned, tools are sterilized and packed, tools are stored, and tools are brought to operation theatres.

All the logistical systems are from hospitals located on the Japanese island Kyushu. All the hospitals are acute general hospitals with almost all clinical areas represented. The sizes of the hospitals are in the range of 400 – 650 beds.

The interviews with the hospital personnel were first conducted with the top management of the hospitals. These interviews were used as a way to get an insight into the hospital, and the focus on what the most important factors to the hospital are, what is the perception of logistics in their hospital, and what role does new technology play to the hospital.

The second round of interviews was conducted with the clinical personnel working at the department involved in the supporting logistical systems. The interviews were focused on determining two major aims: (1) get an insight into how the particular logistical system was built for that particular hospital, as part of this focus was on the quality parameters of the system, and (2) determine the major differences of the system compared to the equivalent Danish system.

As part of the on-site observations the personnel responsible for the logistical system was interviewed on the most important aspects of the system and their perception on technology within the logistics they were responsible for. During the interviews the concepts of the framework was presented and discussed, in order to get an insight into whether the model covered the most important aspects of how Japanese health care personnel perceive logistics and the use of technology in their daily work. Additionally it was studied whether the model was adequate for of assessing the possibility of implementing new technology into logistics.

Further the on-site observations were used to fully document the logistical system from start to end, all the processes involved in the particular logistical system, and the use of technology to perform the tasks of that particular logistical system.

The original framework developed in a Danish context was constructed using two different steps: a deductive process establishing the theoretical foundation using literature survey and an inductive process using semi-structured interviews and on-site observations. The literature survey focused on the literature concerning health care, logistics, and technology. The semi-structured interviews were conducted with staff members from the emergency department and the laboratory at a major Danish hospital.

5. RESULTS

5.1 THE NEW FRAMEWORK

The original framework was constructed as qualitative framework, meaning that the analysis of the logistical system to a large degree consisted of subjective assessment based on guidelines presented in the framework. Testing the framework in a Japanese context showed that the framework needed to be changed from a qualitative assessment framework to a quantitative assessment framework. Transforming the framework made it possible to calculate performance of the logistical system within the areas described in the initial framework. The four areas were transformed into measurable parameters and the parameters were possible to be divided into indicators. The parameters and indicators were developed into a performance assessment model. This model made it possible to measure the performance of the Japanese logistical system as well as it was now possible to measure the Danish systems as well. Using the new model made it possible to make a more direct comparison between the two systems, and thereby pinpoint difference.

The extended model is based on the principles of performance measurement. The aim of the model is to measure the performance of the current logistical system, and assess the potential of implementing new technology into the logistical system. The entire logistical system will be assessed using the model thereby securing that the model is holistic. The performance of the current system as well as the potential of the new technology is calculated using the parameter and indicator structure shown in figure 2.

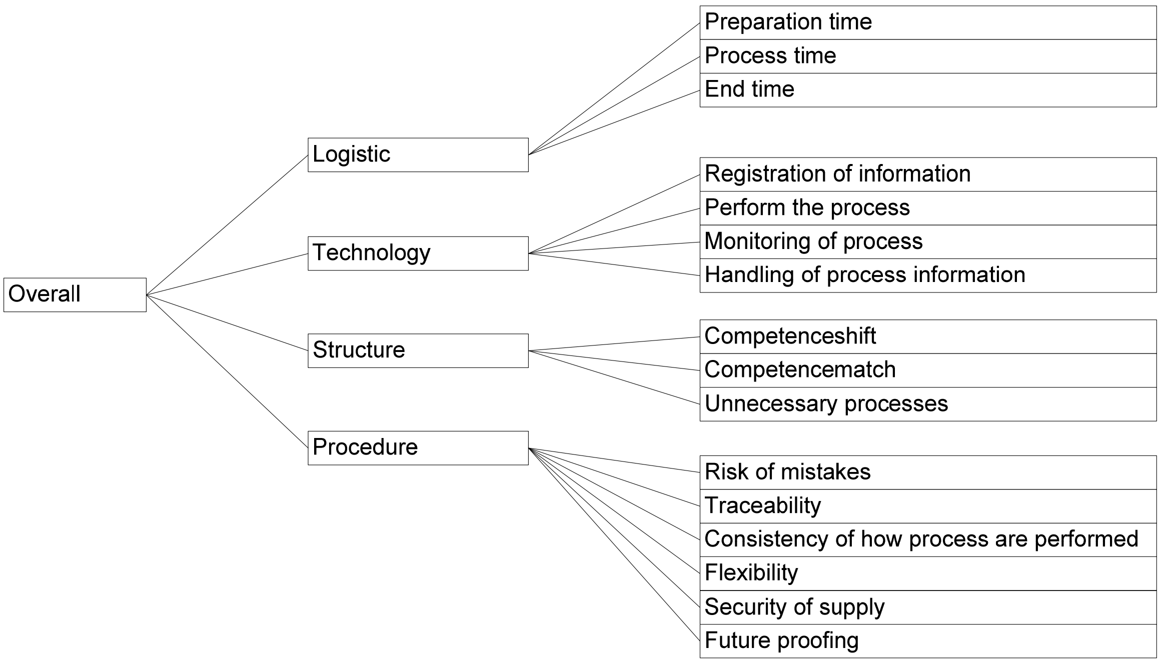


Figure 2. Parameter and Indicator Structure

In order to measure the performance of the system a framework consisting of nine steps has been created. To measure the performance of the system, the nine following steps need to be followed. The nine steps are shown below, and the use of the steps is shown on the example of blood samples taken in the emergency department.

The performance for each of the indicators are calculated in the range of 0 to 1, meaning 0 is the worst obtainable performance and 1 is the best obtainable performance. The indicators are then aggregated based on the weight assigned, and the performance of the parameters will then reflect the performance of the indicators relative to their assigned weight.

1. Identify the logistical system – define what logistical system will be the aim of the analysis.
    - Blood samples taken in the emergency department.
2. State the quality requirements of the system – each logistical system has some quality aspects that need to be fulfilled in order to determine if the system is working appropriately.
    - The blood in the blood samples must not be destroyed during the transportation between emergency department and laboratory.
    - The blood samples needs to be analyzed as fast as possible after blood samples are drawn, since the patients are emergency patients and therefore every second counts.
    - Blood drawing equipment needs to fully sterile.
    - The blood samples must not be exposed to too high temperatures.
    - The blood samples must not be treated to violent.
3. Identify the meta-processes of the system – a logistical system consists of a set of meta-processes, which are the processes that needs to be performed for the system to work.
    - Taking the blood sample in the emergency department.
    - Transporting the blood sample to the laboratory.
    - Analyzing blood sample at the laboratory.
    - Transporting the result back to the doctors in the emergency department.
4. Draw a process map for the specific logistical system – based on the specific case and the meta-processes it is now possible to create a process map containing all processes, and the personnel performing the processes and the location of the process.

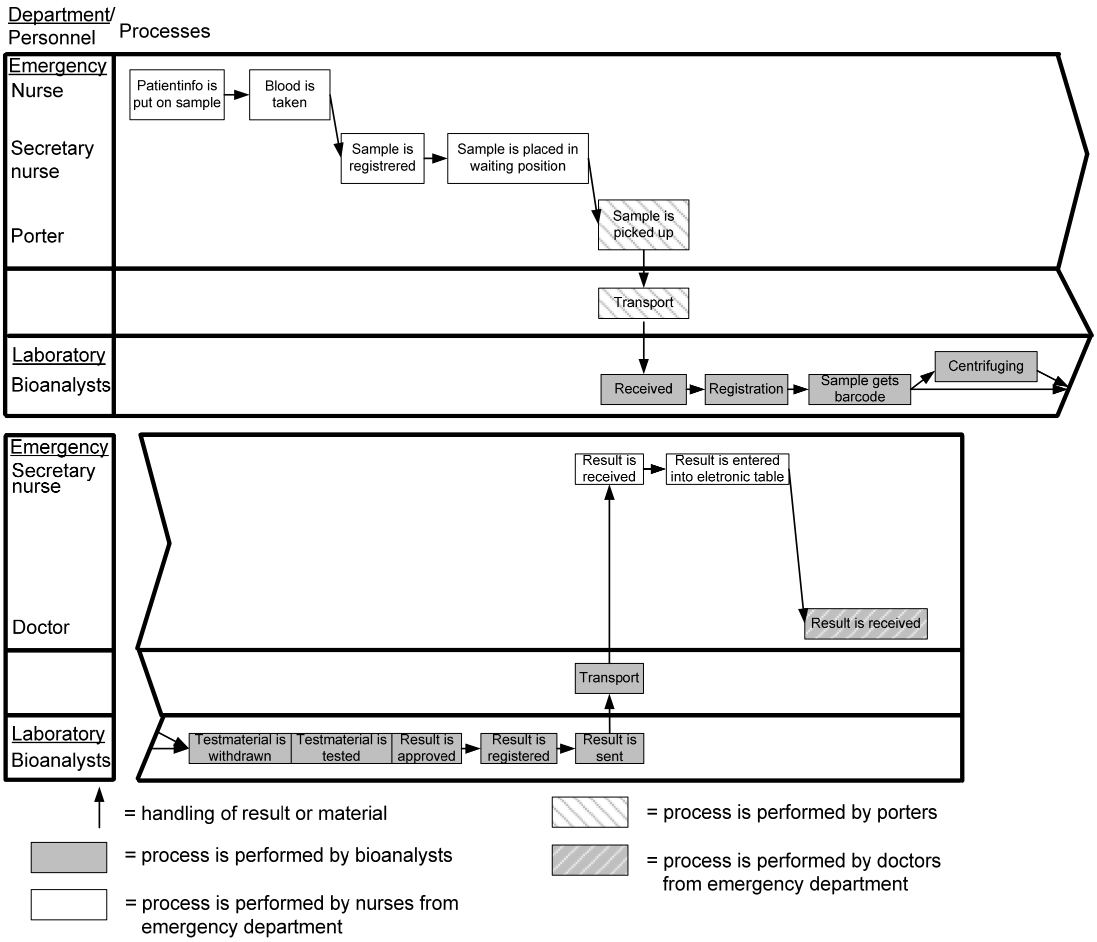


Figure 3. Process Map of Supporting Logistical System

5. Assess the weights of the parameters and indicators – the parameters and indicators need to have a rating in terms of how important they are for the hospital management. The overall performance will thereby reflect the relative importance to the hospital. The weights are rated on a ten-point scale from 1 to 10.

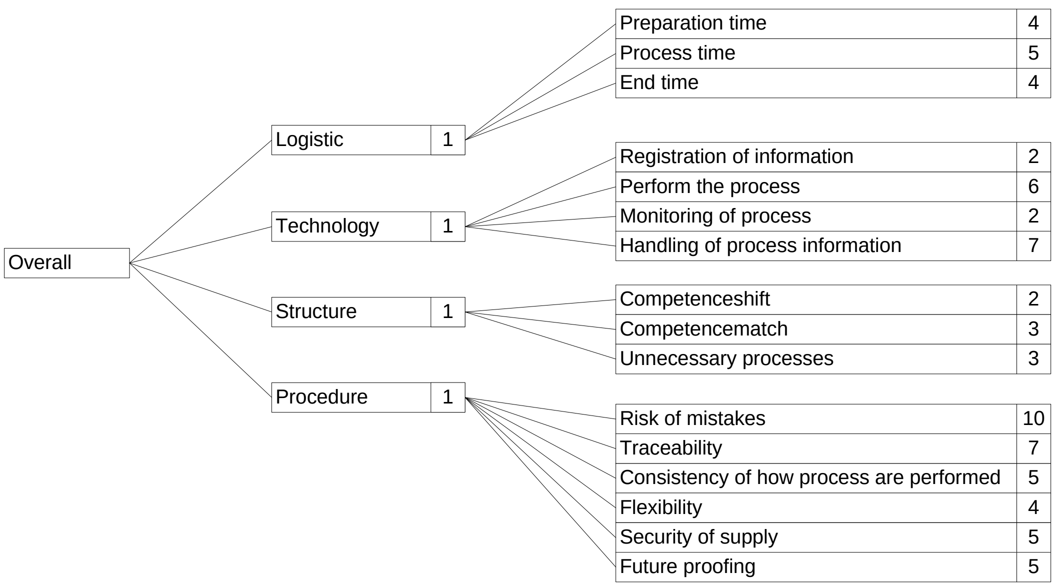
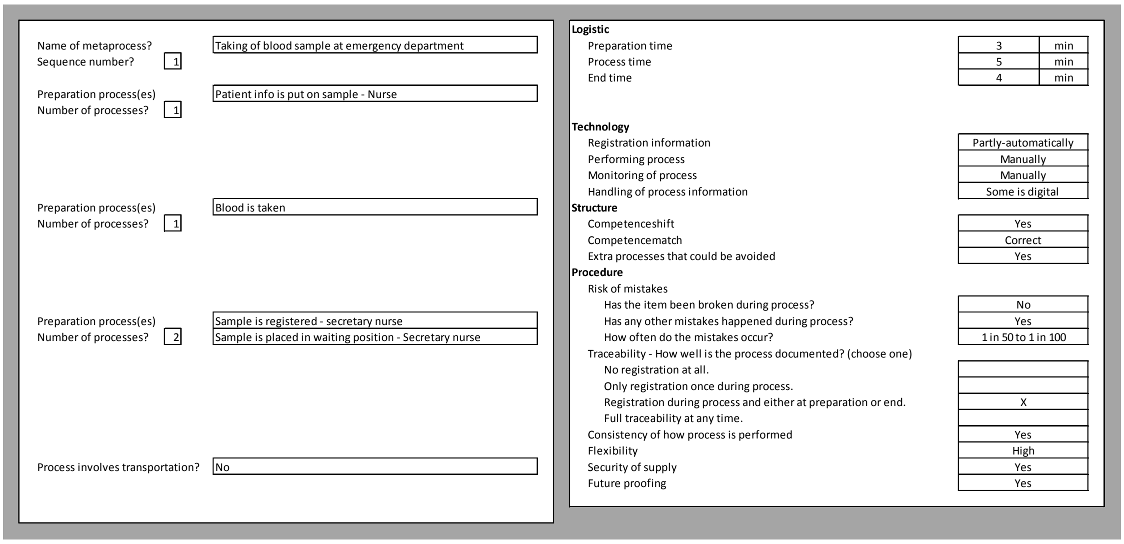


Figure 4. Weights for the Parameters and Indicators

6. Fill out the framework for each of the meta-processes – the indicators can now be filled out and the performance of the system can be determined.


Name of metaprocess? Taking of blood sample at emergency department
Sequence number? 1

Preparation process(es) Patient info is put on sample - Nurse
Number of processes? 1

Preparation process(es) Blood is taken
Number of processes? 1

Preparation process(es) Sample is registered - secretary nurse
Number of processes? 2 Sample is placed in waiting position - Secretary nurse

Process involves transportation? No

Logistic		
Preparation time	3	min
Process time	5	min
End time	4	min
Technology		
Registration information	Partly-automatically	
Performing process	Manually	
Monitoring of process	Manually	
Handling of process information	Some is digital	
Structure		
Competenceshift	Yes	
Competencematch	Correct	
Extra processes that could be avoided	Yes	
Procedure		
Risk of mistakes		
Has the item been broken during process?	No	
Has any other mistakes happened during process?	Yes	
How often do the mistakes occur?	1 in 50 to 1 in 100	
Traceability - How well is the process documented? (choose one)		
No registration at all.		
Only registration once during process.		
Registration during process and either at preparation or end.	X	
Full traceability at any time.		
Consistency of how process is performed	Yes	
Flexibility	High	
Security of supply	Yes	
Future proofing	Yes	

Figure 5. Indicators Filled Out for a Meta-process

7. Locate poor performance in the system – it is now possible to locate the poor performance of the system, and thereby determining where new technology will have the biggest impact.

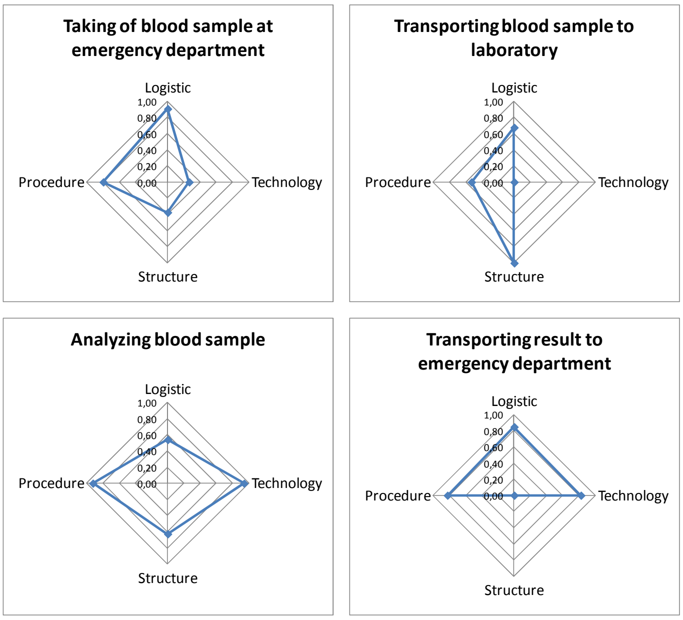


Figure 6. Performance of System

8. Identify possible technologies to improve performance – in cooperation with the employees of the hospital, it is possible to identify technologies that can help improve the poor performance.
   - Alternative 1: Implementing a system so that nurses can scan blood samples quickly and easily after taking them.
   - Alternative 2: Using a pneumatic tube system for transporting the blood samples between the emergency department and the laboratory.

    i. Implement a machine so that samples can be placed directly into the conveyor system of the laboratory analysis machines and thereby use the barcodes already attached to the samples.

- Alternative 3: The result is sent directly to the doctor.

9. Compare performance of the current and the planned system – the old (current system) and the new (planned system) performance can now be compared, and it is possible to assess whether implementing the new technology is sensible.

Overall	Old Performance	0,66	New performance			0,78
Metaprocess 2	Old Performance	0,57	New performance			0,97
Metaprocess 3	Old Performance	0,71	New performance			0,82
Change in time	Old time (min)	89	New time (min)	67	Change (%)	-25

Table 1. Change in Performance Using Alternative 2

Using the framework it is hereby possible to first identify where the system has poor performance, and assess what the potential is from implementing new technology.

5.2 DIFFERENCES IN-BETWEEN DENMARK AND JAPAN

Applying the model to the Danish and Japanese gave the following results.

- The Japanese cases generally had a higher score in terms of controlling information of patient data (blood sample cases).
- However the Danish cases scored higher in terms of controlling information of non-patient related data (surgery tool and bed cases).
- The Danish cases scored lower than the Japanese case for transportation meta-processes.
- The Danish cases scored higher than the Japanese for the technology indicators.

Combining the results obtained from the framework with that acquired during the interviews and on-site observations showed some differences between the two health care systems.

One of the major differences is the sizes of the hospitals. Denmark has made a health care reform (Andersen, Jensen 2010) resulting in fewer but bigger hospitals. On the contrary the Japanese health care system consists of smaller but more hospitals. So the intake of patients is higher per site at the Danish hospitals compared with the Japanese. The result is bigger departments and more complex logistics. The Danish health care sector is thereby relying more on a centralized approach whereas the Japanese is a more de-centralized sector. The difference in sizes of hospitals has a large effect on the technological and logistical solutions implemented at the hospitals.

The Japanese health care sector consists of many outpatient clinics, which acts as the primary care sector. In Denmark the outpatient clinics are smaller units compared to Japan and as a consequence the outpatient clinics in Japan have the capabilities of treating the patients to a larger extent than in Denmark, where the role of the outpatient clinics is that of diagnosing, prescribing medication and refer patient to treatment. If the patient needs to have blood samples taken, the primary care sector doctor will draw these and sent them to the hospital for testing. In Japan when a patient is ill they will go to the outpatient clinic first, and if the outpatient clinic has the necessary capabilities of treating the patient they will do it. In Denmark if the patient needs to have bloods test drawn, the patient will be referred to the hospital where tests will be performed in order to give the patient a diagnosis. During the day when the outpatient clinics are open, the emergency department at the hospital will primarily treat patients that arrive in ambulances. In Denmark the emergency departments have a more central function in terms of diagnosing and treating patients. Further a higher percentage of patients will go directly to the hospital instead of consulting the primary care doctors. As a result the emergency department has a lot more patients in Denmark than is the case of the emergency department in Japan.

One major difference is the use of an integrated information and communication technology (ICT) system in Japan, resulting in the outpatient clinics and the hospitals being able to easily access the same system. For instance it will then be possible order blood sample in the outpatient clinic, and the hospital can access this order. When the patient arrives at the hospital, the reception can get all information regarding the patient in a fast and easy manner. This integrated ICT system is also used within the hospital, so a blood sample is linked to the ICT system using a barcode on the blood samples. In the Danish health care such an integrated system does not exist, instead different ICT systems are used to access different patient information.

The Japanese hospitals rely to a much greater extent on outsourcing logistical assignments than Danish hospitals. Many of the transportation processes were outsourced to outside companies. Examples are such as transportation of samples between wards and laboratory, linen between wards and cleaning area. One of the consequences was that almost all transportation processes were performed manually.

One area with great focus in the Danish health care system is that of documenting everything that happens throughout the system. So if a mistake appears it is easy to pinpoint where the mistake happened, the mistake can be corrected, and other material, item or goods affected by the mistake can be fixed. There was not the same need for documenting in the Japanese cases.

A very interesting difference is the working routines in the two different systems. In the Danish system the personnel is expected to work no more than 37 hours a week, and if they are working overtime the employees will receive overtime pay, and in some cases they will receive extra holiday. In Japan there is no overtime pay and the personnel is expected to work until there are no more patients, making the system more flexible than the Danish.

Additionally it was interesting noticing that the use of robots was almost completely absent although Japan is one of the countries with the most advanced research when it comes to robots.

Considering the Japanese cases compared with the Danish the major differences are the following:

Blood samples taken in the emergency department.

- Very few blood samples are taken in the emergency department in Japan compared to Denmark. As a result it makes more sense to compare the logistics related to the walk-in patients in Japan and the emergency patients in Denmark.

Blood samples taken on patients at the wards.

- Due to the bigger sizes of the Danish case hospitals compared to the Japanese, a lot more blood samples will be taken in this way at the Danish hospitals.

The logistics related to hospital beds.

- In Denmark the patient is put in the bed when he/she arrives in the emergency department, and the bed follows the patient to the wards where the patient is hospitalized. When the patient is discharged the bed will be transported to a cleaning area. In Japan the beds are fixed to the rooms at the departments, and the patient will be transported around the hospital in either a wheelchair or on a type of stretcher. When the patient is discharged the linen will be changed, but the bed will stay in the department.

Logistics of surgery tools.

- The Danish hospitals have operating theatres in connection with the clinical departments, meaning that the operation theatres are spread over the hospital. In Japan all the operation theatres were located close to each other.

It was the impression that the Danish health care system is more inclined to explore new technological possibilities and trying new innovations for changing the hospital logistical supporting flows than Japan. This is however driven by the construction of the hospitals and the health care sector more than the cultural differences. The different approaches to new technology and innovation within logistics at hospitals are to a greater extent related to the size and complexity of the hospitals and the cost of labor.

6. DISCUSSION

This paper explores the possibility of developing a framework capable of assessing the performance of supporting logistics flows at a hospital. The framework were extended from the one developed in a former study in which a qualitative model had been applied to analysis the logistics in the Danish health care system. The aim of the present study was to test the original model on a different health care system and transformed it according to the findings, quickly posted some challenges. The original model was presented in a qualitative way based on subjective perceptions within some defined areas. This type of assessment model did however not correlate with the demands made by personnel in the Japanese health care sector. The framework was therefore extended into a quantitative and qualitative measurement and assessment model, which turned out also to be of great value to the assessment of logistics in a Danish context.

Research related to logistics in hospitals is a very broad field. It is almost impossible to make a model that covers all of these different logistics fields due to the different nature of the hospital logistics. For instance, there are the logistics of patients both inside and outside of the hospital. There is the procurement process of the hospital with the related supply chain and corresponding logistics. There is the logistics of personnel at the hospital. Due to the many different logistics it is of outmost importance to determine specifically what type of logistics is the focus of an analysis model like the one presented in this study.

As a part of constructing the analysis model it was the aim to explore what differences exists between the Japanese health care sector and the Danish, especially in terms of technology used to perform the logistical processes. The research was based on four case hospitals located in the Kyushu area, Japan, which is one of the four main islands – each of which has its own regional culture and differs greatly in aspects such as the economic situations and the population density. As a consequence there are big differences in-between the health care institutions of the islands in general and the hospitals in particular. Since all the hospitals examined in this study are located in a narrow area, i.e., within a 20 km distance, of the same island, there are some considerations in terms of applicability of the results obtained in this study to hospitals all over Japan. It is however the perception that the results presented in the research paints a general picture of the use of technology in hospital logistics in Japan.

Due to the observed influence of complexity of logistics and the labor cost on the willingness to use new technology, a possible relation could be like the one shown in figure 7.

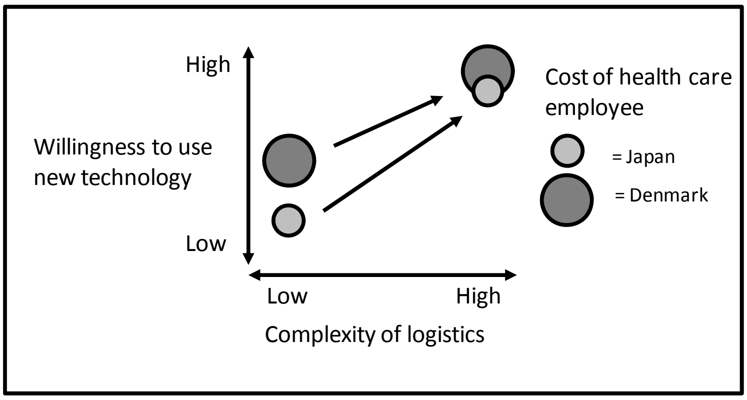


Figure 7. The Correlation between Use of Technology and Complexity of Logistics

Figure 7 shows the observed relation for the Danish health care system (cost of employees is high) and that experienced for the Japanese health care system (cost of employees is medium), which is a result of the difference in working routine. The cost of labor is defined as the cost of one hour of labor. It would in this light be interesting to test whether this relation is valid for other health care systems with cost of health care employee equivalent to that of Denmark and that of Japan. As part of this it is important to define the precise measurements in terms of "Willingness to use new technology" and "Complexity of logistics".

The focus of the research was exclusively on the use of technology in supporting logistical settings at hospitals. The use of technology within the health care sector of Japan on an overall level is not explored, and it is likely that the use of technology within other parts of the health care sector is very different. For instance shows the integrated electronic patient data system a readiness towards the use of technology.

Based on the finding in the research, there are two directions for further studies that could be very interesting to dig into. The first one is to explore the influence of culture on the way the health care system is constructed. As an example could be the influence of culture on the size of hospitals. Secondly it could be interesting exploring the use of technology in health care generally and not limit the focus to logistics.

7. CONCLUSION

The paper proposes a holistic framework for analyzing a logistical system as well as assessing the potential of implementing new technology. The distinctiveness of the framework is the way it has been constructed using performance measure in combination with a logistical analysis and technology assessment. Developing, testing and modifying the framework in a Danish context followed by a testing and modification phase in Japan enhances the output gained from the framework, and thereby adds to the understanding of how continuous improvements can be obtained and measured in healthcare settings.

The framework has two major advantages for healthcare decision makers. Firstly it gives the possibility of making an assessment of a technological change to the current logistical setting, portraying what effect the implementation will have, and which modifications to the logistical settings will provide most operational benefits. Secondly the framework monitors the logistical system, and continuously evaluates the effect of the implemented technology.

Applying the framework to cases from two different countries made it possible to pinpoint some of the major differences in-between the countries. The study showed that the major differences were related to the construction and organization of the respective health care sectors.

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Paper 3

P3: Identifying the potential of implementing technologies in hospital logistics: making emergency department diagnosis more efficient

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Cover Sheet

Article's full title: Identifying the potential of implementing technologies in hospital logistics: making emergency department diagnosis more efficient

Short title: Performance assessment of hospital logistics

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Objective: More than 30 % of hospital expenditure is related to logistics. However, there has not been a systematic approach to how the use of technology can make logistics more efficient. Our research objective is to present an analytical framework capable of analyzing a logistical system and present were the implementation of technology will have the biggest impact and what effect the implementation will have.

Methods: The framework has been developed through interviews with hospital personnel and a literature survey in PubMed and the local university database. Based on these initial findings the framework was tested, modified and verified using 8 case studies from 4 different hospitals, two Danish and two Japanese.

Results: An analytical framework consisting of a performance assessment model is presented. The framework analyzes the logistical systems and assesses the effect of implementing technologies. The logistical system "acute blood samples" is analyzed using the framework and the result of the analysis is presented.

Conclusions: A systematic tool for analyzing hospital logistics and assess the effect of technological implementations is a powerful tool in the quest of making hospital logistics more efficient. Applying the presented framework to a case helped the hospital management identify different improvement potentials, leading to implementation of one of the proposed technologies.

Keywords: Logistics, automation, decision making

Introduction

The healthcare sector is under tremendous pressure in most developed countries. The demographic development and the increased number of chronically ill patients have resulted in rapidly increasing expenditures, thereby demanding that the current system is changed and transformed to cope with the challenges (1).

In Denmark a healthcare reform has been implemented in order to cope with the challenges. One of the major outcomes of the Danish reform is that current hospitals are being radically changed and new hospitals are being constructed. One of the results from the changes is an increased focus on how to construct the logistics in order to make the logistics function in a more efficient manner. In relation to this consideration studies have shown that 30-46 % of hospital expenditures are spent within logistics (2).

In collaboration with hospital management three different issues has been identified in the quest to make more efficient logistics. 1) Internal logistics involving many different departments is not functioning optimal. The approach used to deal with logistics within these settings has usually been approached in a vertical approach, meaning that the logistics have been dealt with in a departmental perspective. As a consequence the logistical interfaces in-between departments are not functioning optimal resulting in logistics being sub-optimized. 2) The use of technology to improve logistics has not been used to the same extend as for example in industry. 3) In healthcare the main use of technology has been related to the clinical areas and treatment of patients.

There is therefore a need for creating a holistic tool capable of analyzing the entire logistical systems across departments. Further there is a need for a tool capable of assessing the potential of implementing technology in order to improve the logistics. In the following study a conceptual model designed to address these issues will be presented.

Theoretical and empirical foundation

The focus of this project is logistics and technology, and a literature survey has been conducted in order to explore the research within these areas. In regard to logistics in healthcare five areas have had the main focus; flow of patients (3), LEAN in healthcare (4), tracking devices in healthcare (5), structuring of hospital/departments (6) and Supply chain and procurement in healthcare (7) The literature on technology in healthcare is focused within seven subjects; quality of treatment (8), treating patients at home (9), better diagnosing (10), ICT in healthcare (11) long-distance treating (12), technology assessment (13) and robots in healthcare (14).

The literature survey confirmed the need posted by hospital management to investigate how technology can be used within logistics at hospitals. The literature concerning tracking devices to monitor and control flows and some of the literature concerning ICT in healthcare was the only literature exploiting the potential of technology to improve logistics.

As a result from the literature survey and the concerns posted by the hospital management the need is for a structured model capable of analyzing logistics and exploiting technological opportunities.

Methodology

The research has been conducted through two main phases; a deductive phase where the foundation for the model was developed using literature survey and preliminary interview with hospital management, and an inductive phase using case studies (15, 16, 17) in order to test and modify model. The literature survey part was conducted by being combining "hospital" and "health care" with "logistics", "supply chain" and "technology". The search was conducted in PubMed and the local university database containing more than 159 million article references from publishers and leading scitech abstract databases. The literature survey and initial interviews laid the foundation for the concepts of the framework.

Conducting the case studies was the main part of the research. The case studies were performed by conducting semi-structured interviews with the personnel (18) and on-site observations (19). The case study included 8 different cases from 4 hospitals, 2 Danish and 2 Japanese. The involvement varied from being involved in testing, modifying and verifying the model, to receiving a full analysis of a specific case with recommendations for changes. The two Danish hospitals have 1250 beds and 1000 beds. Both of the hospitals got a full analysis of their cases. The two Japanese cases have approximately 400 and 650 beds and were involved in testing the model.

At each of the hospitals interview sessions were conducted with three different employee groups; top management, administrative personnel with responsibility of logistics, and clinical personnel. On an overall level the focus of the interviews was two-fold: (1) get an insight into how the particular logistical system was built for that particular hospital, (2) understand how the model would fit in terms with that particular logistical system at that specific hospital.

The interviews with top management were used as a way to get an insight into the hospital, the most important factors to the hospital, the perception of logistics in their hospital, and what role does new technology plays to the hospital. One person from top management from each of the hospitals was interviewed. The interviews with the administrative personnel focused on how they measure the logistical performance, and what was most important in terms of controlling and monitoring the logistical systems. Two persons from each of the Japanese hospitals and three from each of the Danish hospitals were interviewed. The interviews with the clinical personnel focused on the practical implications on a day to day basis. During the interviews the concepts of the framework was presented and discussed. Additionally it was studied whether the model was adequate for assessing the possibility of implementing new technology into logistics.

The on-site observations were used to fully document the logistical system from start to end, all the processes involved in that particular logistical system, and to what extent technology was used to perform the processes.

Conceptual model and aim of research

Based on experience from operations management within both industry and healthcare there is a close relation between the logistic movement of an item from one location to another and the technology used in order to do the movement. Additionally there is a close relation to the organizational structure supporting the movement and procedures needed to be followed. That means a model (see figure 1) can be drawn where the elements logistic, technology, structure and procedure stretch the solution space and the effect measuring the performance of the solution. The entrance to the model is one of these elements. In this case the starting point is the logistic element.

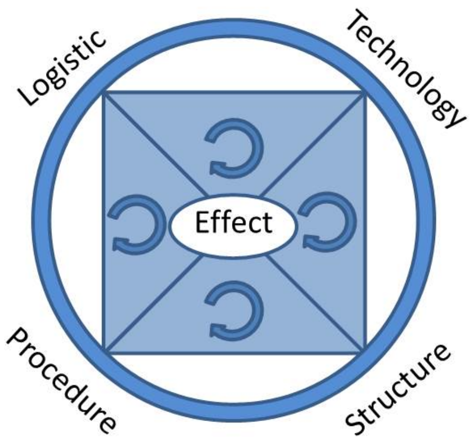

Figure 1: The relation between changes and effect within hospitals

The figure shows that in order to obtain an effect, one of the four elements needs to be changed. Changing this particular element will result in changes within each of the three other elements.

Logistic refers to the transportation of patients or items during processes. Since not all processes involve transportation of items or goods, the logistical area is not relevant for all processes. For processes involving transportation the logistics investigate whether it is possible to make the transportation process in a more efficient manner. For processes not involving transportation focus is on the time spent performing the different part of the process, and the share of inactive time (time where no action is happening).

Britannica online defines *technology* as "…the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment." Based on this definition technology is seen as the ability of implementing measures that can help the employees in performing the process in a more automated and less manual manner.

Structure is the available competences of the employees and the organization used to help perform the processes. In that sense the structure is used as the investigative measure to determine whether the organization is constructed in order to secure that the process is performed in the most efficient manner. Additionally structure looks into whether the correct competences are available in order to perform the process.

Procedure focuses on how the process has been constructed in order to secure that the system and the quality requirements are in compliance. Procedure therefore both relates to the risk of making mistakes, but also how well the process copes with outside changes affecting the process.

The importance of these four elements in relation to operational changes happening at a hospital makes it interesting to investigate whether it is possible to create an assessment model that can be used to assess the performance of the logistical system within these elements. Additional it is of interest to identify what effect changes to the logistical system will have within each of these elements. Therefore the aim of this project is to look into what the relation is between logistics, technology, structure and procedure, and what effect changes within one element will have on the other elements. In order to do so it has been the aim to develop a framework that can be used to analyze a logistical system, and determine what is the potential effect when making changes to this logistical system.

Logistical systems in health care

In this project a *logistical system* has been defined as a patient flow, a resource/employee flow, an information flow and a supporting flow. The patient flow is the main and most important flow as it initializes the other flows. The resource flow focuses on the different employees available for performing the treatment process. The supporting flow is the flow of items and materials used in relation to the patient flow but not directly involving the patient, as the name indicates, it supports the patient flow, see figure 2.In some cases the patient and the supporting flow runs concurrently. In other cases the patient flow cannot continue before the supporting flow is executed.

Each flow can be divided into a number of well-defined and delimited phases or meta-processes. An example of a meta-process for the patient flow is diagnosing of a patient. Diagnosing a patient is not just one process but a sequence of processes e.g. testing the patient, interpreting the result, etc. Therefore a meta-process can further be divided into a number of processes. These processes can be grouped within the meta-processes as either a pre-process, the process itself or as a finishing/ end-process. The meta-processes secure that the logistical system is represented in a more holistic and better manner in relation to technology, structure and procedures.

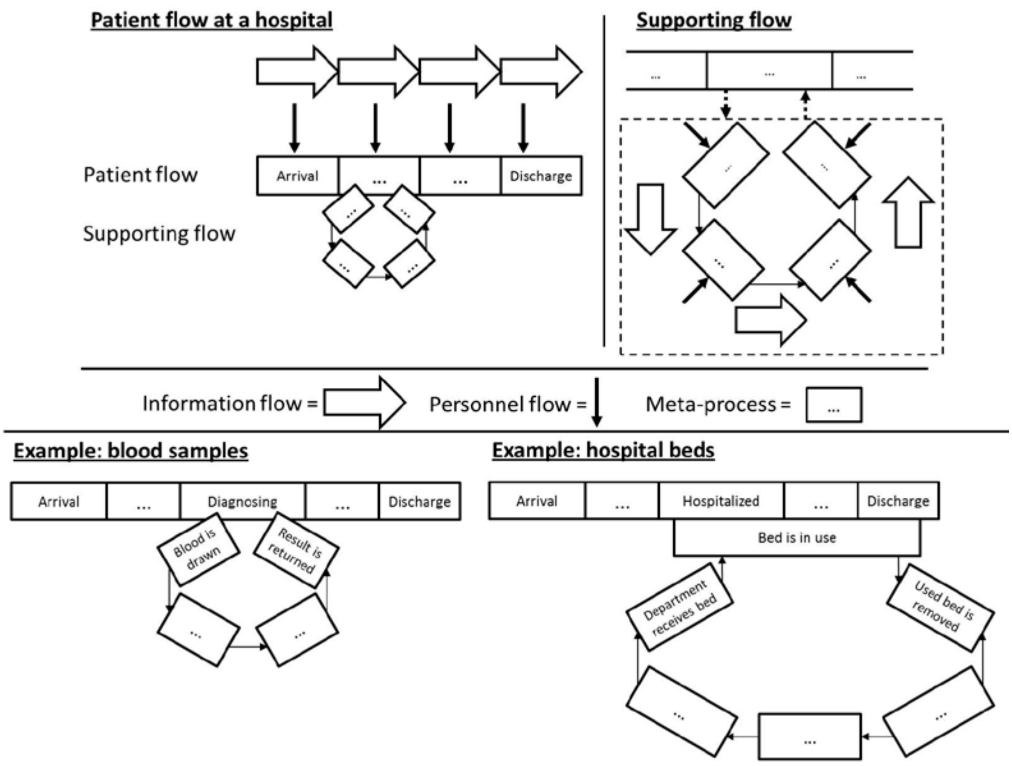

Figure 2: Patient flow, initiated flows, and example of supporting flows

Considering the supporting flow it is however important to acknowledge that there is a related information flow and personnel flow. Additionally there might also be some additional supporting flows related to the meta-processes of the supporting flow, see figure 2. In this study the focus is the supporting flow and the relation between the logistic, technology, structure and procedure for the supporting flow.

There are two different types of supporting flows. There are supporting flows, which are initiated by the patient flow, and ends when interacting with the patient flow again. One example is the flow of blood samples taken in the emergency department. The flow is initiated when the blood sample is taken and ends when the result is delivered to the emergency department (see figure 2). In this case the patient flow cannot continue before the supporting flow ends.

The other types of flows are flows which become integrated in the patient flow, and follow the patient flow through some processes e.g. bed logistics. In this flow one of the meta-processes is locked to the patient flow and the processes is finished whenever the patient flow releases it (see figure 2). In this case the patient and the supporting flow runs concurrently after initialization.

However the two different types of flow are similar in the manner that they go through a number of processes after being initialized by the patient flow until interacting with the patient flow again. It is this part of the supporting flow that is the focus of this study, since this part of the supporting system will help optimizing the patient flow. As a consequence the supporting flows can be considered as "back office" processes.

Based on the four elements and the importance of the supporting logistical flow, a framework capable of analyzing and determining the potential effect of changes has been developed.

Framework

The aim of the framework is to present a standard procedure for analyzing a logistical system, locate where the system can be improved, and generate and test ideas on how to improve the system.

The framework consists of the following eleven steps:

1. Identify the logistical system
2. State the quality requirements of the system
3. Identify the meta-processes of the system
4. Draw a process diagram for the specific logistical system
5. Assess the weight of the indicators and the performance criteria
6. Fill out the performance assessment model for each of the meta-processes
7. Locate poor performance in the system
8. Identify possible technologies to improve performance
9. Fill out the performance assessment model for the proposed technologies
10. Compare performance of old and new system
11. Economically assess whether the changes are feasible

The eleven steps of the framework can be grouped into three different groups. Step 1-7 focuses on analyzing the current setup. Step 8-10 are part of the idea generation with the aim of improving the current setup. Step 11 explores the possibility of implementing the ideas, and the economics involved in the implementation. Step 11 is solely performed by the hospital and the method for conducting this economic analysis is not part of the framework.

The performance assessment model is based on the four elements. Each of the elements consists of measurable indicators. The performance of the indicators gives the performance of the elements, and this is then used to assess the overall performance (see figure 4).

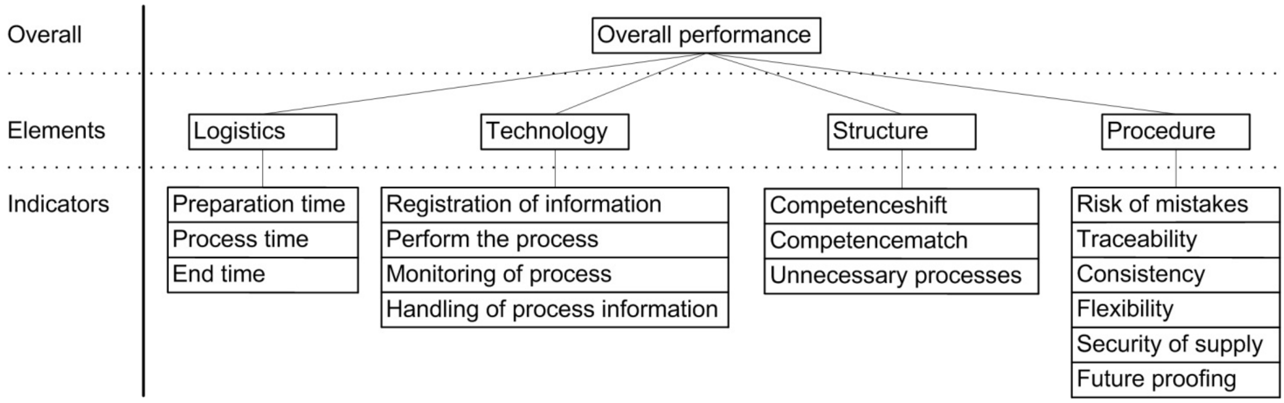

Figure 3: Hierarchy of the 4 elements and related indicators within the performance assessment model

The performance of the indicators are measured on a scale from 0 to 1, 0 being the worst obtainable performance and 1 being the best obtainable performance. Each of the indicators contains a performance measuring question. The answer to this question determines the performance of that particular indicator, and can thereby be used to calculate the overall performance.

The indicators are grouped into five different groups depending on how the performance is measured.

(1) Time measurement: performance is measured as the ratio of inactive time compared to overall process time for that particular meta-process. (2) Observation: performance is measured by exploring how the process is performed, and then assessing whether the observed procedure is in accordance with the performance assessment criteria. (3) Process analysis: performance is measured using the process map created for the supporting flow. (4) Data extract: performance is measured using data that can be extracted from the hospital databases in order to determine performance. (5) Assessment: performance is determined by assessing whether the meta-process is in accordance with the requirements posted in the indicators belonging to this category. In order to carry out the assessment inside knowledge of the process is needed.

In order to get as true an insight as possible into the performance of the system, each of the indicators is weighted relatively in comparison with the other indicators. This is done in order to secure that the indicators considered as the most important at the hospital have the greatest impact on the overall performance. The weighting is done on a scale from 1 to 10. The weighting is performed by the hospital personnel and is done in accordance with their perception of what is important.

Framework in Practice

One of the essential supporting flows at a hospital is the acute blood samples taken in the emergency department. In the following the main results from applying the framework to this case is presented.

Quality requirements

- The blood in the blood samples must not be destroyed during the transportation between emergency department and laboratory.
- The blood samples need to be analyzed as fast as possible after blood samples are drawn, since the patients are emergency patients and time is a crucial factor.
- Blood drawing equipment needs to be sterile.
- The blood samples must not be exposed to too high temperatures.
- The blood samples must not be treated to violent.

Meta-processes

- Taking of blood sample at emergency department
- Transporting blood sample to laboratory
- Analyzing blood sample
- Transporting result to emergency department

Using the meta-processes as the starting point, a process map of the entire system is constructed, see figure 4.

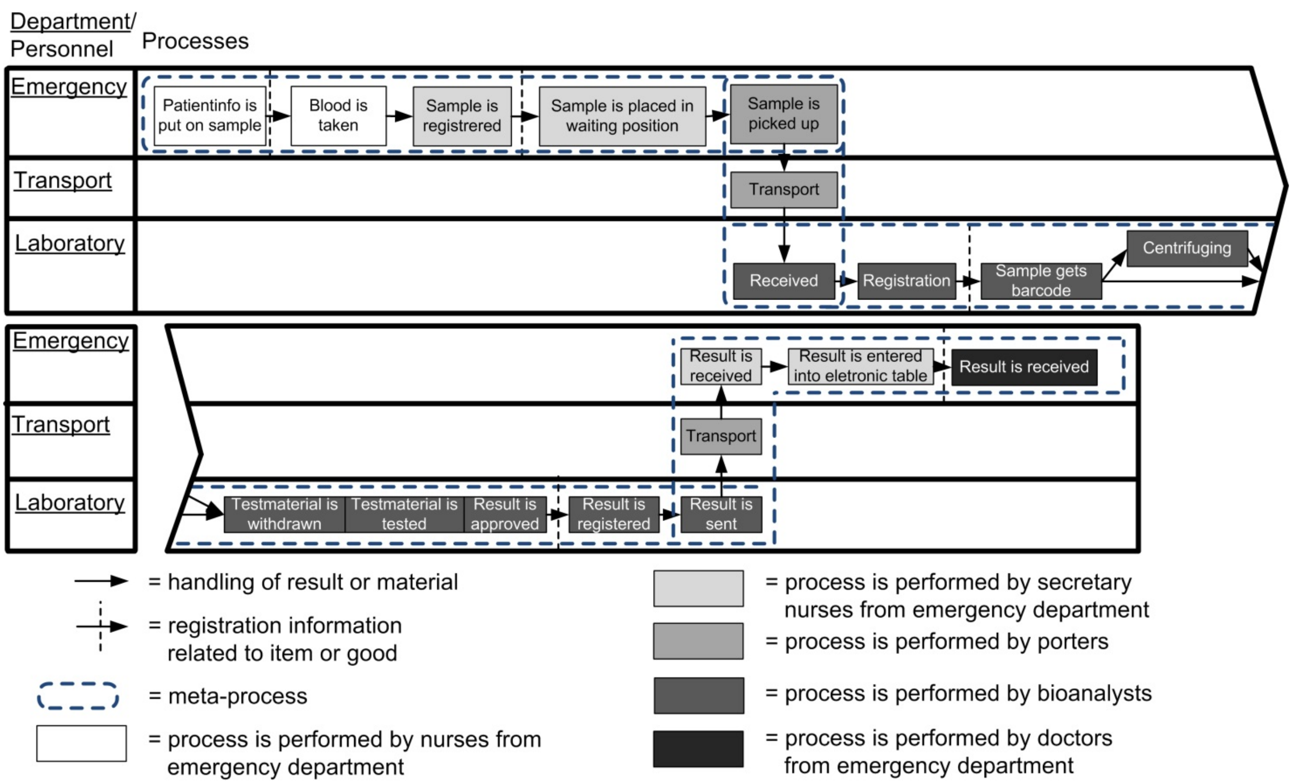

Figure 4: Process map

Overall and meta-processes performance

- Overall: 0,64
- Taking of blood sample at emergency department: 0,61
- Transporting blood sample to laboratory: 0,43
- Analyzing blood sample: 0,91
- Transporting result to emergency department: 0,61

Technological changes

- Implementing a system so nurses can scan blood samples quick and easy after taking them.
- Using a pneumatic tube system for transporting the blood samples between emergency department and laboratory.
    - Presuppose implementation of pneumatic tube system, implement a machine so the samples will be placed directly into the conveyor system of the laboratory analysis machines and thereby use the barcodes already attached to the samples.
- The result is sent directly to the doctor, who receives the result on a portable device.

Performance assessment of technologies

- Technology 1: Performance was improved to 0,69
- Technology 2: Performance was improved to 0,73
    - With a receiving machine at the laboratory performance was improved to 0,75
- Technology 3: Performance was improved to 0,72

Based on the analysis of the technologies, the hospital chose to further investigate the possibilities of using a pneumatic tube system as well as a machine used for receiving blood samples at the laboratory.

Economical assessment

As a result of the analysis the hospital made an economic assessment of the consequence from implementing a pneumatic tube system. The economic analysis consisted of an analysis of the immediate effect of changing the procedure and an analysis of the side effects on a hospital level. The basic outcome from the economical assessment is the following:

It was estimated by the hospital involved, that the immediate impact of implementing the pneumatic tube system and the implementation and installation cost are approximately € 70.000, based on experience from other Danish hospitals. The company responsible for repair and maintenance has estimated these costs to € 2.000 annually. The annual savings in terms of employees is estimated to € 40.000. The hospital has therefore estimated that the investment will be saved within two years.

Additionally the hospital estimated the potential economic side effects as a result of implementing a pneumatic tube system were linked to two outcomes from the implementation. 1) The throughput time from blood sample is taken until result is ready would lead to a decrease in the length of stay for the patients, which would result in a reduction of cost. 2) The new flow of blood samples to the laboratory will lead to potential of optimizing the processes in the laboratory. The total economic potential of these two outcomes have not been determined.

Discussion

Developing a model like the one presented in this study poses some issues. The two major issues identified is 1) the generalizability of the model and 2) securing that the model covers all important aspects to be included in such an analysis. In terms of the generalizability the model has primarily been built and tested in relation to the healthcare system in Denmark. The Danish cases have been heavily involved in testing and validating the model in accordance with their needs and experience. However the model has provided the Danish hospitals with an analysis that has led to changes being implemented. In order to test whether the model is also applicable in other settings, the model has been tested on four different cases from Japanese hospitals. The testing and validation lead to minor modifications of the model, but on overall level the model seemed applicable to the Japanese cases. However the Japanese hospitals have not had the same stakes in the project, and as a result have not adopted the results in the same manner the Danish hospitals have.

Determining whether all aspects are covered in the model poses a dilemma. Firstly it is important to secure that all important aspects are covered, but at the same time it is important to secure that the model is not overly complex. Having a model that is very complex discourages the hospital management from using the model thereby making the model uninteresting. The approach taken to secure this has been by using continuous dialogue with the hospitals, and trying to get as many different inputs as possible. Three different employee groups have been involved in order to secure this; top management of the hospital, administrative management being responsible for the logistical system, and the clinical personnel dealing with the logistical systems on a daily basis. All three groups have been involved in terms of what inputs are the most important, and how the input should be analyzed. The clinical personnel have however not been involved in terms of how the output is presented and interpreted. Using this approach secures that all clinical stakeholders in the logistical system have had their saying in the construction of the model, and that the model shows an accurate picture of the performance of the system.

One thing that it is important to state in relation to the model is the applicability. Although the model is constructed around logistics in healthcare, it has only been developed and tested on the supporting logistical flows, and not the logistics at an overall level. There is the possibility that the model would give an accurate picture of other types of logistical systems, but this has not been tested in the creation of the model. It could however be of great interest to do this in future research.

As stated earlier the model and results gained from the model has been validated in continuous discussions with the healthcare personnel. However the results from the analysis have also been tested in relation to a simulation study conducted by the researchers. The results from the simulation study were in line with the results obtained in this study.

Conclusion

The framework has through its testing and validation evolved in to a trustworthy tool for the hospital managers. The analysis and conclusion obtained using the model has been the foundation for changes being implemented or in the process of being implemented for three of the cases involved. The section of this paper concerning "Framework in Practice" is an example of how the analysis has led to changes actually being implemented at the hospital. The results obtained from implementing the pneumatic tube system has been in line with the results predicted in the model. The implementation has had a great impact, and other departments dealing with the transportation of samples are interested in using the framework in order to exploit the potential of a pneumatic tube system.

One of the Danish hospitals has been so enthusiastic about the framework, resulting in the framework currently being developed into a set of rules for how to evaluate future logistical systems. The hospital is one of the hospitals that are going to be expanded, and the new logistical systems will then be constructed in line with the requirements presented in the model.

Conflicts Of Interest

All authors report they have no potential conflicts of interest.

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Paper 4

P4: Assessing the potential of technology in hospital in-house logistical systems – identifying improvement potential using an analytical framework

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Title: Assessing the potential of technology in hospital in-house logistical systems – identifying improvement potential using an analytical framework

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Abstract:

This paper presents an analytical framework enabling the possibility of assessing the potential of implementing new technology into hospitals in-house logistics. In the continuous process of making health care more efficient the combination of technology and logistics has been a useful tool. However within the logistics at hospital there is a lack for a structured tool assessing the potential of technologies. Concurrently logistical systems at hospital have been approached on a departmental level leading to sub-optimization of the system.

The analytical framework presented in this paper is designed so it can assess the performance of a logistical system at hospitals as well as evaluating the potential of implementing new technological initiatives. The framework analysis the entire logistical system, thereby securing a holistic overview of the system as well as give the opportunity of obtaining information concerning the performance on a more detailed level. In the paper the framework is applied to the case of the logistics of hospital beds at a major Danish hospital.

Keywords: Performance assessment, logistics, technology implementation, hospital management

Introduction

The health care sector of many developed countries is facing huge challenges due to the change in health care need. Demographic development and lifestyles in these countries have led to a higher demand for age-related health care and health care related to chronic diseases. Simultaneously, many of these countries suffer from the financial crisis, which have resulted in an increase in public and health care spending. As a consequence, there is an emerging need for making health care sectors more efficient. The largest part of health care expenditure is related to hospitals. Therefore, there is a growing focus on how to make the hospitals more efficient. Studies show that 30-46 % of total expenditure at hospitals is related to logistics (Poulin, 2003), and as a result there is a large potential for making logistics more efficient.

Within industry focus has been on how to make the logistics more efficient by using technology. This has proven to be a viable approach, but it has, however, not been utilized in the same structured manner within health care. Additionally, logistics at hospitals have been approached in a departmental (vertical) manner leading to sub-optimization (Shumaker, 2007; Mayfield, 2009).

As a result there is a need for a structured approach to determine the potential of technology to make the logistics more efficient at hospitals. Concurrently, there is a need for a structured and practical approach that considers the entire logistics, securing a holistic insight. The research presented in this article focuses on how a practical model can be developed by taking these considerations into account.

Logistical systems in health care

A hospital consists of many different logistical systems. The main system is the patient flow. In order to make the patient flow function in an optimal way, three types of different flows or logistical systems are initiated to secure the execution of the patient flow. The three flows are; a resource/employee flow, an information flow and a supporting flow. The resource/personnel flow focuses on the resources and employees available for performing the treatment process. The information flow relates to the information generated in the execution of the process. The supporting flow is the flow of items and materials used in relation to the patient flow but not directly involving the patient. As the name indicates, it supports the patient flow, see figure 1.

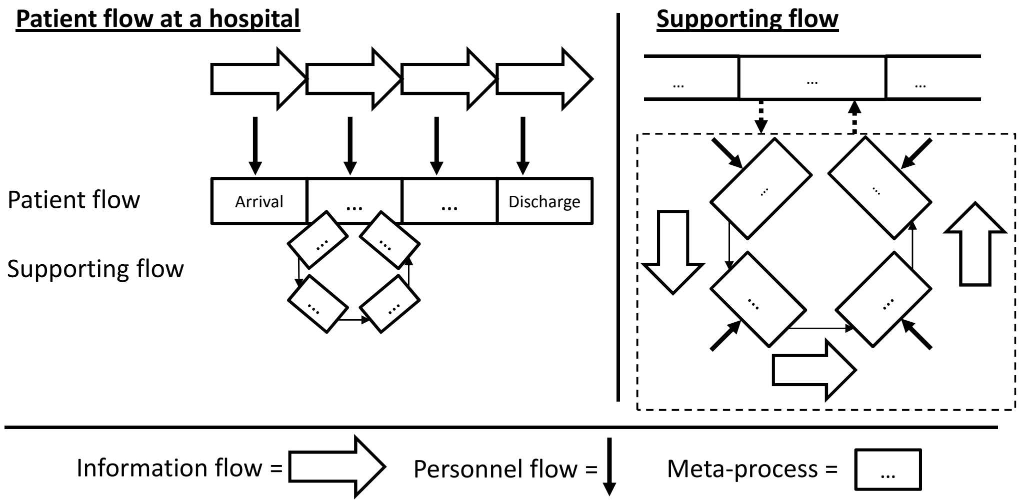

Figure 1: Patient flow and initiated flows at a hospital

A logistical system can be divided into a number of well-defined and delimited phases or meta-processes, an example is diagnosing of a patient. Diagnosing a patient is not just one process but a sequence of processes, e.g. testing the patient, interpreting the result etc. Therefore, a meta-process can further be divided into a number of processes. These processes can be grouped within the meta-processes as either a pre-process, the process itself or as a finishing/end-process. The meta-processes secure that the logistical system is represented in a holistic manner.

The focus of this study is the supporting flows. The supporting flows are initialized by the patient flow and are very important due to the impact on the patient flow. Figure 2 shows two examples of a supporting flow. In the blood sample the patient flow cannot continue before the supporting flow is finished whereas in the hospital beds example the supporting flow is initialized by the patient flow, but they are executed independently. This makes the supporting flows essential in order to secure an optimal patient flow and make the hospital function in the best manner.

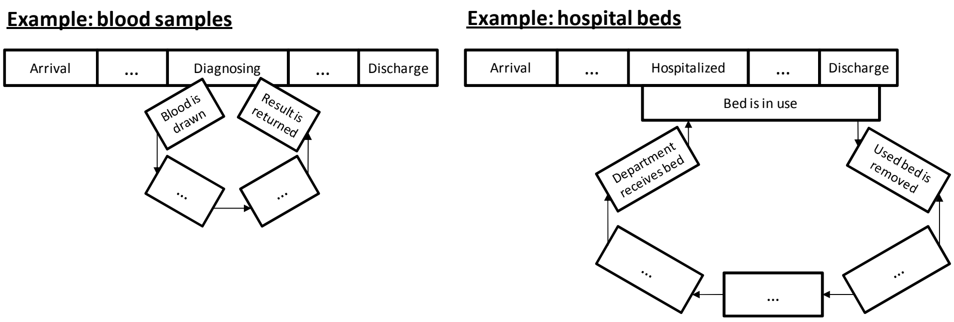

Figure 2: Example of supporting flows at a hospital

Link between Logistics and Technology in Health Care

The hospital personnel involved in this research has experienced that the following four elements are essential in relation to operational changes to logistical systems at hospitals; logistics, technology, structure and procedure. This resulted in development of figure 3.

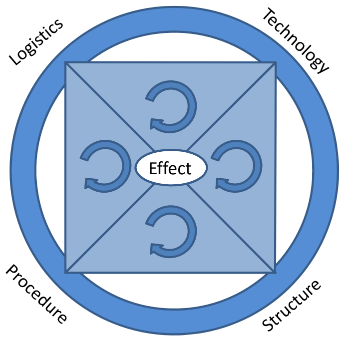

Figure 3: The relation between changes and effect within hospitals

Each of these areas is interrelated, so in order to obtain an effect, one of the four elements needs to be changed. Changing this particular element will result in changes within each of the three other elements.

Related to the supporting flow it is used to create an assessment tool that can be used to assess the performance of the supporting flow within these elements. Additionally, it is of interest to identify what effect changes to the supporting flow will have within each of these elements.

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Structure is the available competences of the employees and the organization formed to perform the processes. In this sense structure is used as an investigative measure to determine whether the organization is designed to secure the most efficient process performance. Additionally, structure looks into whether the correct competences are available in order to perform a given process.

Procedure focuses on how the process has been constructed in order to secure that the system and the quality requirements are in compliance. Procedure therefore both relates to the risk of making mistakes, but also to how well the process copes with outside changes affecting the process.

Using these relations as the offset, a literature search was conducted, focusing on the relation between logistics and technology in health care.

The literature concerning logistics in health care is mainly focused within five different areas; flow of patients (Banerjee et al, 2008; Fitzgerald et al, 2011) , LEAN in health care (Souza, 2009; Dickson et al, 2009), tracking devices in health care (Pokharel, 2005; Poland et al, 2011) , structuring of hospital/departments (Villa et al, 2009) and Supply chain and procurement in health care (Dooley, 2009; Logan et al, 2010). Furthermore, some focus has been on how to improve logistics by using simulation (Brailsford et al, 2009; Gunal, 2012). The literature on technology in health care is focused within seven subjects; quality of treatment (Barbash & Glied 2010; Bowater et al, 2011), treating patients at home (Brennan et al, 2009; Polisena et al, 2009), better diagnosing (Okamura et al, 2010; Sadaka et al, 2012), ICT in health care (Spil et al, 2011; Issel et al, 2012), long-distance treating (Berlinger, 2006; Okamura et al, 2010), technology assessment (Sampietro-Colom et al, 2012; Kidholm et al, 2012) and robots in health care (Stein, 2009; Nejat et al, 2009).

The exploration of literature showed little research with focus on how to examine the potential of technology within logistics in health care settings. The only literature that had some link between technology and logistics was the literature concerning ICT in health care. The results obtained from the literature survey were in line with the perception of the health care professionals participating in the research.

As a consequence, some conceptual ideas on how to exploit the potential of technology within hospital logistics have been developed (Jørgensen et al, 2012) based on the ideas presented in figure 3. In the present research these thoughts will be further developed into an applicable tool, and the tool will be tested in a real life case.

The aim of this research therefore consists of two parts; a theoretical and a practical aim. The theoretical part focuses on the relation between logistics, technology, structure and procedure regarding supporting flows at hospitals. As part of this an analytical framework will be developed enabling the analysis of supporting flows within the four elements. The most important part of the analytical framework is the development of a performance assessment tool enabling assessment of the performance of the logistical system. The practical part of the study is concerned with testing the framework on a real case in order to test the validity and applicability of the framework.

Methodology

Based on the above-mentioned aims the research presented will go through four phases:

1. Identify the most important aspects when dealing with technology and logistics in supporting flows.
2. Develop measurable indicators corresponding to what is considered as the most important aspects.
3. Construct a structured framework containing the measurable indicators, thereby making the framework usable and applicable.
4. Analyze the robustness of the framework on a real life case, thereby determining the applicability of the framework. The case chosen for testing is bed logistics.

The first phase is performed by using a combination of literature survey and semi-structured interviews (Winter, Munn-Giddings 2001) with hospital personnel and on-site observations (Maaloe 2002). The literature part focuses on the literature concerning health care, logistics and technology.

The second and third phase consists of semi-structured interviews, in which the ideas developed by the researchers are discussed and verified by the hospital personnel. The two phases occur continuously as new ideas are tested and changes to the ideas are implemented and verified.

The fourth phase consists of on-site observations and semi-structured interviews with the personnel involved in the bed logistics.

8 cases from 4 different hospitals are involved in the first three phases of the research, but with different levels of involvement. Three employee groups are interviewed during these three phases. The top management of the hospitals is involved in order to get an insight into the hospital, the most important factors at the hospital, and to know how management perceived the role of logistics at their particular hospital. Further, the role of technology is investigated. The second group is the administrative personnel responsible for the logistics on a day-to-day basis. The focus of these interviews is on how the logistics are measured and monitored, and on the tools and means used to control and secure logistics. The last group interviewed is the clinical personnel. Focus in these interviews is on the implications logistics have in relation to the tasks they performed.

The involvement of the hospitals varies from being involved in testing and modification of the indicators and the model to getting a full analysis of the particular case with recommendation for changes.

Cases	Size of hospital	Country	Involvement
Hospital A - Transportation of acute blood samples - Bed logistics - Logistics of surgery tools	1200 – 1300 beds	Denmark	- Analysis of cases - Recommendations presented to hospital - Recommendations implemented
Hospital B - Transportation of planned blood samples	1000 – 1100 beds	Denmark	- Analysis of cases - Recommendations presented to hospital - Recommendations implemented
Hospital C - Logistics of surgery tools - Transportation of planned blood samples	400 – 500 beds	Japan	- Testing and modification of the model
Hospital D - Transportation of acute blood samples - Bed logistics	500 – 600 beds	Japan	- Testing and modification of the model

Table 1: Involved cases and level of involvement

Performance assessment tool

The performance of a logistical system is the sum of the performance of each of the meta-processes included in the system. The structure of the performance assessment tool is based on the concepts from OEE (overall equipment efficiency). The overall performance is calculated using the performance of the elements, which furthermore is based on a set of indicators, see figure 4.

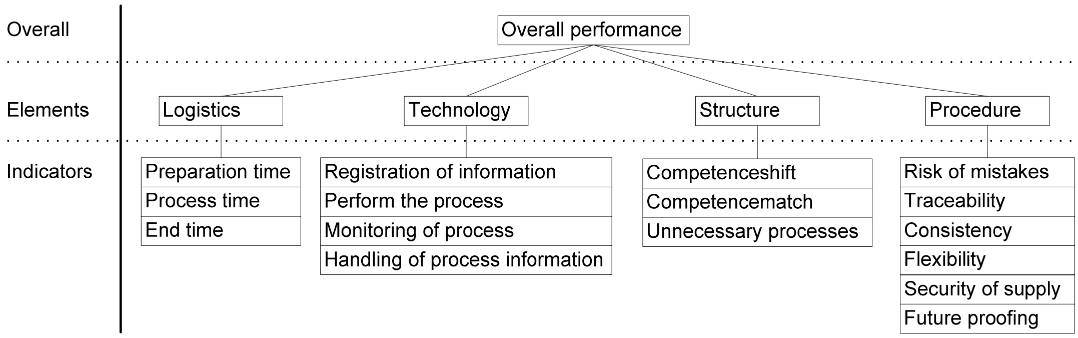


Figure 4: Performance hierarchy

An indicator can be characterized by five attributes; (1) the name, (2) the element under which it is located, (3) the corresponding category, (4) the performance assessment question (Q_x) and (5) the performance assessment criterion. Figure 5 shows the indicator matrix containing all the indicators and the attributes for each indicator.

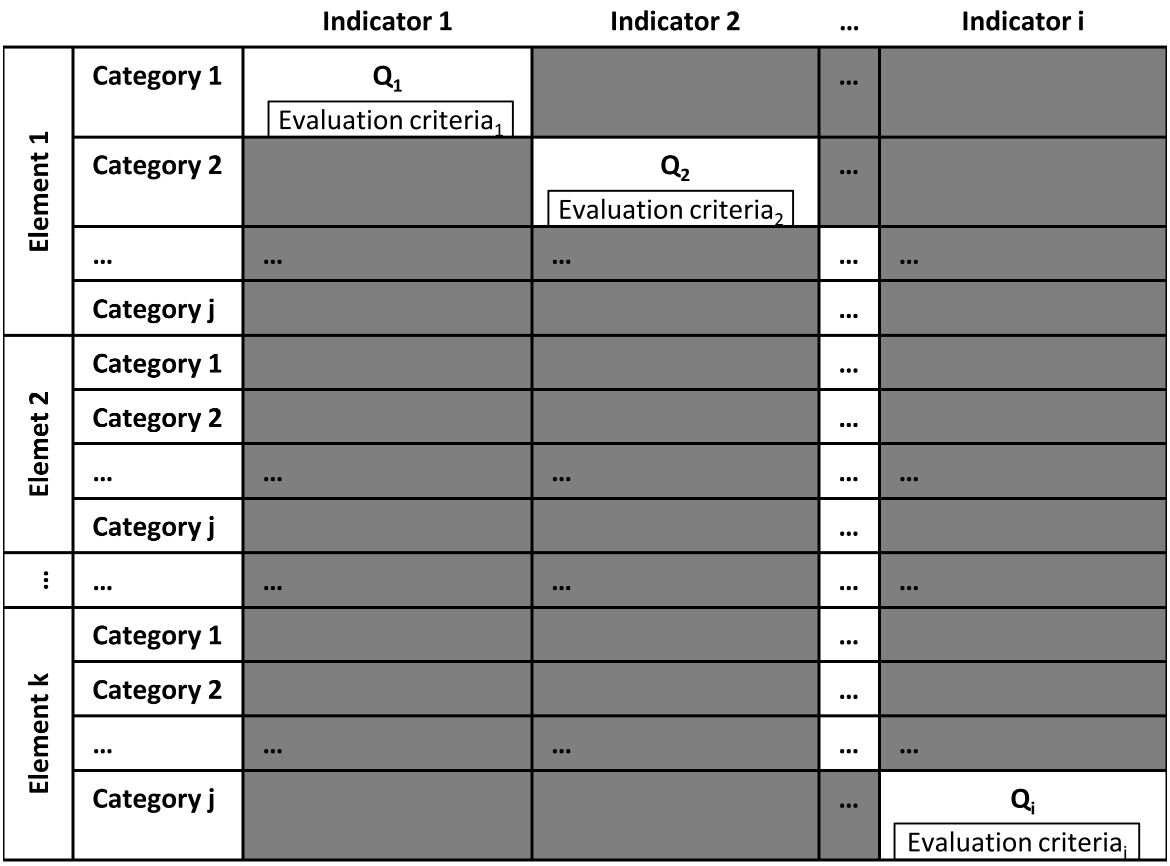


Figure 5: Indicator matrix

The *indicator name* is the name of the indicator, and *element* is the group under which the indicator is located. The current research operates with the four elements of logistics, technology, structure and procedure.

Each indicator is assigned within an *indicator category* according to how performance is calculated.

In order to calculate the performance of the indicators each indicator is assigned a *performance assessment question*. How to obtain the answer is related to the category of the indicator.

In order to calculate the performance of the indicator the *performance evaluation criterion* is determined. The performance of each indicator is calculated on a scale where 1 is the best obtainable result, and 0 is the worst obtainable result. The performance assessment criteria vary according to the indicator category. For a certain category the extremes can be "yes" or "no", and for others the extremes can be measurable limits.

In this study 16 indicators are identified, see figure 4, and five different indicator categories are created. (1) Time measurement: performance is measured as the ratio of inactive time compared to overall process time for that particular meta-process. (2) Observation: performance is measured by exploring how the process is performed, and then assessing whether the observed procedure is in accordance with the performance assessment criteria. (3) Process analysis: performance is measured using the process map created for the supporting flow. (4) Data extract: performance is measured using data that can be extracted from the hospital databases in order to determine performance. (5) Assessment: performance is determined by assessing whether the meta-process is in accordance with the requirements posted in the indicators belonging to this category. In order to carry out the assessment inside knowledge of the process is needed.

In figure 6 the indicator matrix is created for all the indicators within the structure element. All the five attributes are easily obtainable from the indicator matrix.

		Competenceshift	**Competencematch**	**Avoidable processes**
Structure	**Time measurement**			
	Observation	**Do the responsibility of the process change during the process?** 0 | ———— | 1 Yes No	**How is the match between requirement of personnel qualification and the actual competence?** 0 | ———— | 1 Lower Higher Fit	
	Process analysis			**Do the meta-process contain unnecessary processes?** 0 | ———— | 1 Yes No
	Data extract			
	Assessment			

Figure 6: Example of indicator matrix for the Structure element

The performance assessment criterion is central for measuring the performance of a meta-process within the different indicators. It is therefore important to understand the construction of the performance assessment criteria. The performance assessment criterion for the indicators “Preparation time” and “Registration of info” is presented in figure 7.

Logistic – Preparation process

Score	**0**	**0,2**	**0,4**	**0,6**	**0,8**	**1**
Criteria	**> 50 %**	**40 – 50 %**	**30 – 40 %**	**20 – 30 %**	**10 – 20 %**	**< 10 %**

Tecnology – Registration of info

Score	**0**	**0,5**	**1**
Criteria	**Manually**	**Partly-automatic**	**Automatically**

Figure 7: Performance assessment criterion for the indicators ”Preparation time” and “Registration of info”.

Figure 7 shows the performance assessment criterion for two very different indicator categories, namely “Time measurement” and “Observation”, and the criteria are as a result very different. However, using the performance criteria makes it possible to compare the performance within the two different categories. As a result, the performance criteria are very important when comparing the performance of two different indicators, and it is therefore extremely important that the performance criteria are carefully chosen and thoroughly evaluated in order to get as true a picture as possible.

In order to apply the performance assessment tool comprehensively and investigate the benefits of implementing a new technology, a structured approach have been developed, and an analytical framework has been constructed.

Analytical framework

The analytical framework is a standard procedure for analyzing a supporting flow in order to assess the current performance as well as assessing the potential of implementing a new technology. The analytical framework consists of 11 different steps;

1. Identify the logistical system – define which logistical system will be the aim of the analysis.
2. State the quality requirements of the system – each logistical system has some quality aspects that need to be fulfilled in order to determine if the system is working appropriately.
3. Identify the meta-processes of the system – a logistical system consists of a set of meta-processes, which are the processes that need to be performed for the system to work.
4. Draw a process diagram for the specific logistical system – a process map containing all processes can be created using the specific case and the meta-processes, as well as who performs them and where they are performed.
5. Assess the weight of the indicators and the performance criteria – the indicators need to have a rating in terms of how important they are to the hospital in question, and the performance criteria need to be defined. The overall performance will thereby reflect the relative importance to the hospital. The rating is done using a scale from 1-10.
6. Fill out the performance assessment tool for each of the meta-processes – the indicators can now be filled out and the performance of the system can be determined.
7. Locate poor performance in the system – it is now possible to locate the poor performance of the system and thereby determine where new technology will have the biggest impact.
8. Identify possible technologies to improve performance – in cooperation with the employees of the hospital it is possible to identify technologies that can help improve the poor performance.
9. Fill out the performance assessment tool for the proposed technologies – based on the technologies proposed it is possible to fill out the assessment model and thereby get an estimate of what effect the changes will have.
10. Compare performance of old and new system – the old and new performance can now be compared, and it is possible to assess whether implementation of new technology is sensible.
11. Assess feasibility of the changes planned – based on the proposed technological changes it is possible for the hospital to make an assessment in terms of the cost of implementing the technological changes. In combination with the projected benefits in performance the hospital can then decide whether to implement the technological changes or not.

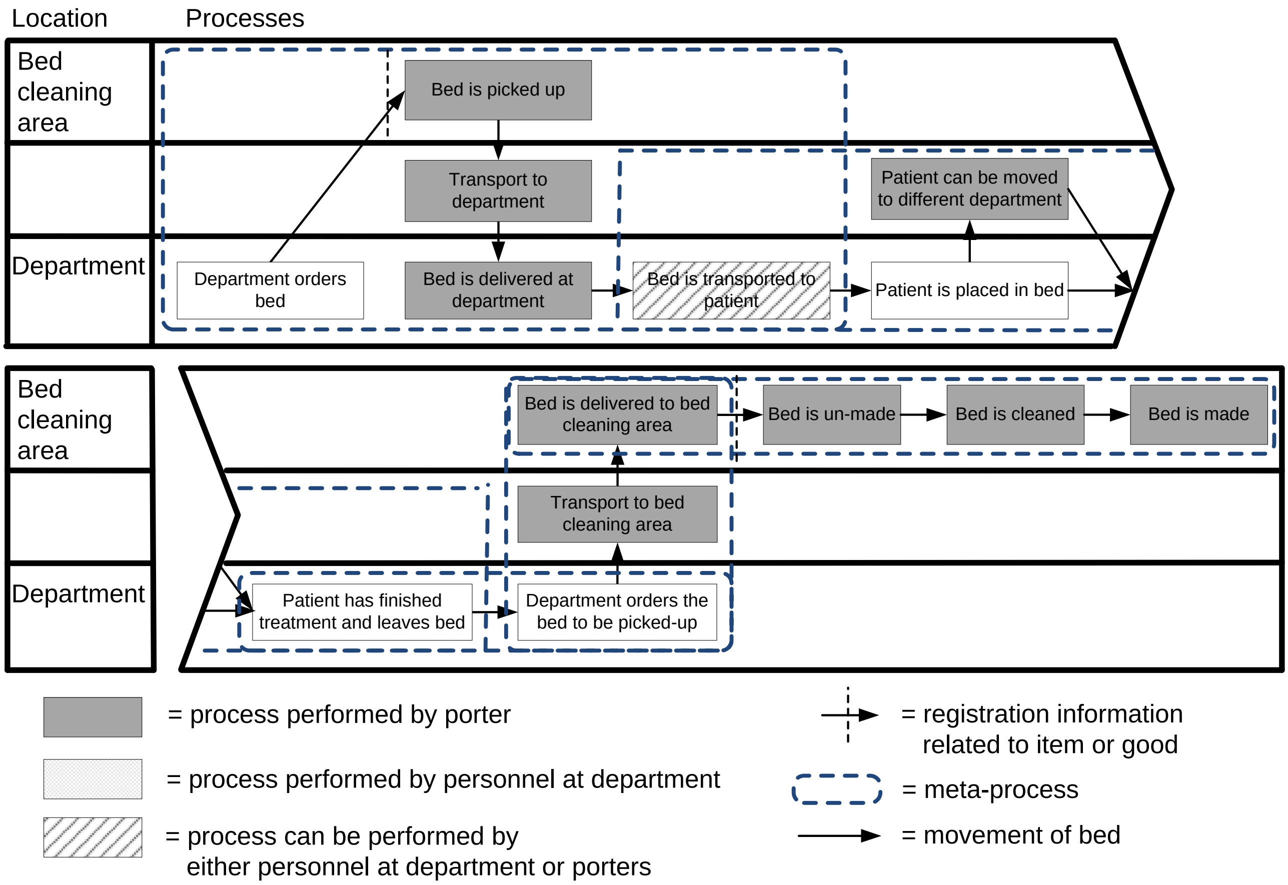
The eleven steps of the framework can be grouped into three different groups. Steps 1-7 focus on analyzing the current setup. Steps 8-10 are part of the idea generation with the aim to improve the current setup. Step 11 explores the possibility of implementing the ideas and the financial aspects involved in the implementation. Step 11 is executed by the management at the hospital who uses the outcome of the first ten steps as supporting information to decide whether or not a technology should be implemented, and which technology will have the biggest impact.

Analyzing bed logistics

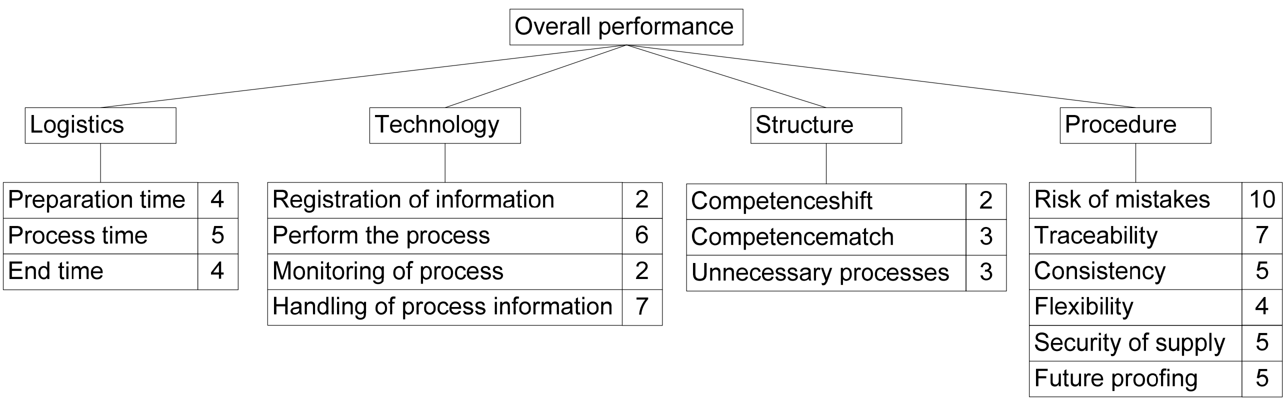
The performance assessment tool and the analytical framework have been tested on the logistical system of hospital beds logistics. The analysis will be presented in the following section.

Hospital beds are extremely important. If a bed is not available, the patient cannot be treated, which can lead to unfortunate results. If a treatment cannot start, employee time is wasted and a rescheduling is necessary. Another aspect is customized beds. Some elderly and weak patients have a need for special mattresses, because the use of normal mattresses can lead to pressure sore. These mattresses are very expensive compared to the normal mattresses, and as a result the hospitals have limited numbers of these special mattresses. It is, therefore, of utmost importance to have fully control of where the mattresses are so the patients in need can get them.

1. Logistical system – Bed logistics
2. Quality requirements
    a. Securing that the bed is available when needed.
    b. Bed and mattress should fit the patient condition.
    c. Bed is properly cleaned.
    d. Full overview of clean and unclean beds.
3. Five meta-processes have been identified for the bed logistics.
    a. Bed is transported to patient.
    b. Patient is placed in bed and bed is in use.
    c. Patient is discharged and leaves bed.
    d. Bed is transported to cleaning.
    e. Bed is unmade, cleaned and made.
4. Process map of the current situation.



5. Weight of indicators.



6. The performance obtained for the entire system and each of the meta-processes is presented in table 2.

Process	Performance
Overall	0,57
Bed is transported to patient	0,54
Patient is placed in bed and bed is in use	0,59
Patient is discharged and leaves bed	0,68
Bed is transported to cleaning	0,51
Bed is unmade, cleaned and made	0,51

Table 2: Performance of the overall system as well as the performance of each of the meta-processes

7. Four issues have been identified as having the biggest negative impact on the performance.
    a. A general lack of integrated information system. There is no overview of where the clean and unclean beds are located.
    b. There is also a lack in terms of ordering beds for planned patients.
    c. There is a lot of waiting time in the transportation processes.
    d. The cleaning process is very time consuming, and the conveyor belt transporting the beds is very fragile.
8. In order to address the issues behind the poor performance the following technological solutions could help solve the problems:
    1. Implementing a tracking system to ensure complete overview of the position of the beds.
    2. A system were the beds can be registered as clean or unclean, in order to make it possible to identify the location of unclean beds. This system requires that technology 1 be implemented.
    3. Using robots to transport empty beds. Requires the implementation of technology 1 and 2.
    4. Implementation of an automatic washing and cleaning system for the beds.
    5. Use a more flexible type of conveyor belt system for the transportation of beds in cleaning area. An example could be some type of moving walkway.

9. and 10. The following results were obtained for the different technologies:

Technology	Performance
Current	0,57
Technology 1	0,71
Technology 2 (incl. 1)	0,74
Technology 3 (incl. 1 and 2)	0,87
Technology 4	0,63
Technology 5	0,61

Table 3: The Performance of the current situation and the performance of the technologies different

11. Based on the results obtained from the analysis the hospital has investigated the possibilities of implementing an information control system, enabling the hospital to get complete overview of all the beds at the hospital. Additionally, the hospital is investigating the possibilities of using robots for handling the transportation of the beds, as well as different automatic bed washing machines. However, there is currently not a thorough financial evaluation of the different solutions.

Discussion

Conducting this type of research poses some challenges. Does the analysis give a comprehensive and correct picture of the current situation? Are the identified benefits from implementing the new technology in accordance with what will actually be obtained? These questions have been considered and addressed by a very rigorous approach to the development of the performance assessment model and the analytical framework. In the development phase continuous validation and verification processes of each part of the framework and the model have been conducted. Furthermore, the results from the analysis of the current situation have been examined in order to make sure that they correspond with the experience of the hospital personnel.

Although the case of bed logistics is thoroughly described in this paper, other cases have been analyzed using the analytical framework and performance assessment tool. The results obtained in these cases have been used in the validation and verification process of the framework and the tool. In one case the analysis has resulted in one of the proposed technologies being implemented.

In connection with the development of the performance assessment tool and the indicators there are some additional concerns that need to be taken into account in order to ensure the validity of the tool. First of all, it is very important so ensure that the correct and comprehensive elements have been identified. The elements act as guidance for determining what areas have the most impact on the logistical system, as well as ensuring that the logistical system gets evaluated in relation to the quality requirements for that particular system. The second issue is whether the correct indicators are chosen. The indicators are the backbone of the performance assessment tool. There are a couple of issues that need to be considered when choosing the indicators. It is important that all important quality requirements are included in the indicators, thereby ensuring that the measured performance is in compliance with the actual situation. Additionally, it is very important to create performance criteria for the indicators that are in line with what is considered good and bad performance for that particular indicator. If any of these concerns are not fully considered, the performance assessment tool will not give a realistic picture of the performance, and the hospital can end up making wrong decisions. The approach used to address these concerns in this study is to make a continuous evaluation and verification of elements, indicators, criteria and the measured performance with different personnel groups from the hospital.

Concerning the generalizability of the model there are some concerns to consider. The model has been developed in close collaboration with Danish hospitals, with the risk of becoming a model only applicable for Danish hospitals. As a consequence, the model was further tested on two different Japanese hospitals in order to test whether the model was applicable in very different settings. The results indicated that the model also has merit in other settings.

Because the health care sector is under increasing pressure and due to the constant development of new types of technologies, there is a need for hospital managers to make quick decisions about whether or not to make changes. In that respect the analytical framework and the performance assessment tool give hospital managers the possibility to evaluate and compare different technologies quickly and transparent.

One of the important issues to be aware of when constructing performance tools with a hierarchical structure like the one presented is the risk of indicators being interdependent. The performance of some indicators can be covariate, resulting in initiatives having a double influence on the overall performance.

This has not been comprehensively addressed in this study, but has very interesting potential for future studies.

The model has been developed and tested on the supporting flows as described. However, it is likely that the analytical approach of this method is also applicable in regard to other logistical systems than just the supporting flows. This has, however, not been tested, and could be an interesting topic to dig further into in future research.

Conclusion

The two main aims of the study is to develop an analytical framework for analyzing supporting flows at hospitals and apply the analytical framework in a real life case. In order to make such an analytical framework the article presents a systematic approach for outlining logistics at hospitals. This approach makes it possible to both maintain a holistic overview of the logistic system as well as making it possible to get a more detailed insight into the system. Based on the outline of the logistical system an analytical framework containing eleven steps is presented. The core of the analytical framework is the performance assessment tool that makes it possible to assess the performance of the entire logistical system by assessing each of the meta-processes included in the system.

Additionally, the article presents an example of how the analytical framework functions by testing it on the case of bed logistics. The entire analysis of the bed logistics is shown, and the outcome from each step is presented, ending with recommendations on how to improve the bed logistics. As a result of the analysis, the hospital has started investigating the financial perspectives of the presented solutions.

As a result of the research, one of the involved hospitals has started using the analytical framework and the performance assessment tool as a basis for how the future logistics should be constructed when the hospital is expanded. This is done by transforming the framework and the model into a set of guidelines describing the aspects to consider concerning the logistics and how to assess the different possible solutions.

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Paper 5

P5: Improving Blood Sample Logistics using Simulation

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Improving blood sample logistics using simulation

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Abstract

Using simulation as an approach to display and improve internal logistics and handling at hospitals has great potential. This research will show how a simulation model can be used to evaluate changes made to two different cases of transportation of blood samples at a hospital, by evaluating different scenarios against the current situation.

The simulation showed that big potential could be obtained by changing the current approach, implementing a pneumatic tube system showed that a reduction in transportation of up to 35 % could be obtained.

Keywords: Hospitals, logistics, optimisation

Introduction

The healthcare systems in most of the developed countries are experiencing increased pressure due to the demographic development (OECD, 2007). Concurrently the financial crisis has resulted in many countries having to make big cutbacks on their health care spending. As a consequence hospital managers need to make their hospitals more efficient in order to cope with the increased intake of patients and less funding. One approach used in making the hospitals more efficient is looking at the procedures performed, and analyze whether they can be performed in a more efficient manner. In this regard the internal logistics at hospitals is an area where it is possible to make changes in order to improve the efficiency of hospitals.

One of the most important tools in diagnosing and monitoring patient’s illnesses and diseases are analysis of the patient’s blood. As a consequence it is of utmost importance that the blood drawn from the patient is analyzed as fast as possible and that the result is completely reliable. The development of blood testing equipment has therefore undergone tremendous development, and currently it takes less than half an hour to make most of the analysis for a patient. In many cases the time it takes to do the analysis is no longer the process that take up most of the time spent, from the blood is drawn from the patient until the doctor receives the result and diagnosis the patient. In an efficiency manner this has the unwanted outcome that patients are filling up beds unnecessarily, and thereby is an extra cost to the hospitals.

Hospitals therefore have a large interest in getting an analysis of their logistical system related to the blood samples, in order to determine where the system can be improved, and what the consequences of the improvements will have on the entire system. One way of doing this is using simulation or modelling tools.

Simulation and modelling was originally designed as a tool for the production industries, but it has also been widely used within health care (Brailsford et al., 2009, Fone et al., 2003, Forsberg et al., 2011). The focus of the simulation research has been related to many different areas but with most focus on areas such as hospital scheduling, planning and resource utilization. Doing simulation studies in health care is therefore not a new topic. The interesting part is however that only a few of the studies have actually led to implementations of the results discovered in the simulation, according to the findings made by Brailsford et. al (2009) “Each modelling study was rated according to a three-level scale of implementation: 1: Suggested (theoretically proposed by the authors); 2: Conceptualised (discussed with a client organisation); 3: Implemented (actually used in practice). The number of articles rated in each category was Suggested 171 (50%); Conceptualised 153 (44.7%); Implemented 18 (5.3%).”

It is therefore very interesting to look at research that was followed by implementations, and exploit what convinced the hospital managers to implement the changes. The focus of this research is to show how a simulation model displaying an internal logistical system at a hospital can be created and used in terms of making the logistics more efficient.

Blood Testing

The earlier a disease or illness is diagnosed the better treatment doctors can give their patients. Since blood analysis is a crucial part in the diagnosing of patients, the time it takes from blood is drawn until result is received by doctor can have a great influence on the patient treatment. Analysis of blood samples have improved greatly over the last decades, both in terms of the accuracy of the analysis, but also in terms of how long time the analysis takes before result is ready. Earlier an analysis of a blood samples could take many hours or even days, but within the last decade the time of analysis has been decreased to take less than one hour, sometimes as short as 15 minutes. This constitutes completely new requirements to the time spent on the other parts of the blood sample logistical system. From being a part of the system that took a relatively short time, the transportation process is in many cases the part that takes the longest time. Hence there is a great demand for exploring new approaches of doing the transportation, in order to cut down on the time and thereby reducing the diagnosis time for patients.

At Danish hospitals there are two groups of patients that get their blood tested and analyzed as part of their diagnosis and treatment, and where it is very important that the result of the test is available as fast as possible.

The fist group are the patients that arrives at the emergency department and where the blood test will constitute a crucial part in the diagnosis of the patients illness and thereby the treatment that the patient should undergo. When a patient arrives in the emergency department in Denmark the patient is diagnosed and initial treatment is started. When the diagnose has been established then the patient will be sent to the department which is specialized in treating patients with this particular type of disease or with a disease in that particular part of the body. It is therefore very important that the diagnosis of the patients can be done as soon as possible.

The second group of patients is the hospitalized patients. Each of the departments at Danish hospitals has hospitalized patients. These patients have some disease that is so severe that the patient needs to stay at the hospital or need to undergo some recovery after treatment that needs to be monitored at the hospital. In both of the cases analysis of the blood is a very important tool in the monitoring of disease and recovery. All samples are taken on blood taking rounds, meaning that a very long time can pass from the blood samples taken in the beginning are delivered to the laboratory.

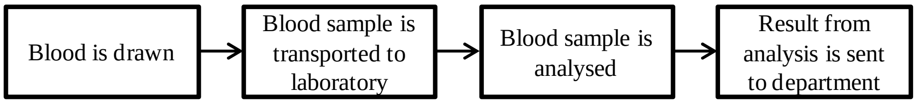

Figure 1: Overall phases involved in taking blood samples

Each of the overall phases consists of many different processes that depend on the patient type, and the technology used in performing the phase. The overall phases are the phases that the blood samples have to go through from sample is drawn until result is ready for the doctor to state diagnosis.

Why simulating blood sample logistics?

The research presented in this paper has a theoretical and a practical aim. The theoretical aim is to test the feasibility of using simulation to address logistical challenges in health care settings. Simulation tools have originally been developed to model industrial systems for analyze, optimize and implement new ideas, but simulation is also being widely used to simulate various health care systems. Therefore it is necessary to address the logistical system of a hospital in the same manner as a logistical system would be in an industrial setting. This has the implication that health care personnel doesn’t consider hospitals as an institution that can be compared with a factory, airport etc. As an outcome there is a high risk of the personnel having doubts about the obtained results. Consequently it is very important to consider this issue in the construction phase of the simulation, and therefore interesting to elaborate on in retrospect.

The practical aim is in relation to the two cases. The hospitals responsible for each of the cases are very interested in getting an analysis of their current state, as well as having an evaluation of the effect of implementing different changes.

As a consequence of the two aims of the research, four overall points are used as the guidelines in the research.

1. In which parts of the system is the major time consumption?
2. Which of these processes is it possible to change?
3. Identify different technologies that can perform the process.
4. Determine the effect of making the changes to the system.

Methodology

All the data used in the simulations were provided by the two hospitals involved in the project. Further all the results obtained from the simulations were reviewed by and approved by the hospitals.

The methodology used in this research can be perceived as empirical research (Karlsson, 2009) within quantitative modelling. The aim of the research is to give hospital managers a basis for making the most optimal solution based on the situation they are in. The research takes it starting point in the current situation of two specific logistical systems.

A value stream mapping of the system was then created to pinpoint the non-value adding processes of the system and which of these takes the longest time. The next step was in collaboration with the personnel of the hospital to identify different technologies that can perform or even eliminate the non-value adding processes. Using the different technological possibilities as the offset, it is then possible to create various scenarios of how the logistical system will be affected based on the implementation of the technology. For each of the technological implementations, scenarios was created corresponding to possible resource use.

To create all the different scenarios a simulation tool was used. First a simulation for the current situation was created. This model was presented to the personnel at the hospital in order to validate the results, as well as convince the personnel of the applicability of simulation in describing their hospital. Using the initial model as a starting point, models were developed for each technological possibility. For each technology the optimal use of resources was determined, e.g. the optimal numbers of AGVs.

In creating the simulation models large amounts of data was used. The model was developed so it exactly matched the layout of the actual hospital. Using a detailed blueprint of the hospital, it was possible to get an exact layout of the different floors at the hospital with exact distances. Further due to extensive on-site observations the time used in performing clinical tasks were also included in the simulation model, as well as velocity of personnel, time used riding and waiting for elevators.

The data used were collected by the laboratory personnel performing the blood test, data extracted from the databases at the hospitals, and people from industry with knowledge regarding the different technologies.

In both cases a simulation model corresponding to the current situation was constructed, tested and determined whether it showed the correct picture. This ensured that the new simulation models showed an accurate picture of the consequences of implementing new technology.

Description of particular simulation cases

The first case relates to blood samples taken in the emergency department (emergency case). All the blood samples are acute, meaning that it is not known when and how many samples need testing. After a patient arrives at the emergency department he/she is registered, and the nurse at the reception makes a triage (an assessment) of how critically ill the patient is. After the triage the patient will undergo the first test in order to give the patient the correct diagnosis. The blood sample is a large part of this, and for the case hospital approximately 90 patients are diagnosed in the emergency department each day using blood samples. The processes involved in the

The processes involved in the transportation of blood samples between emergency department and laboratory are shown in figure 2.

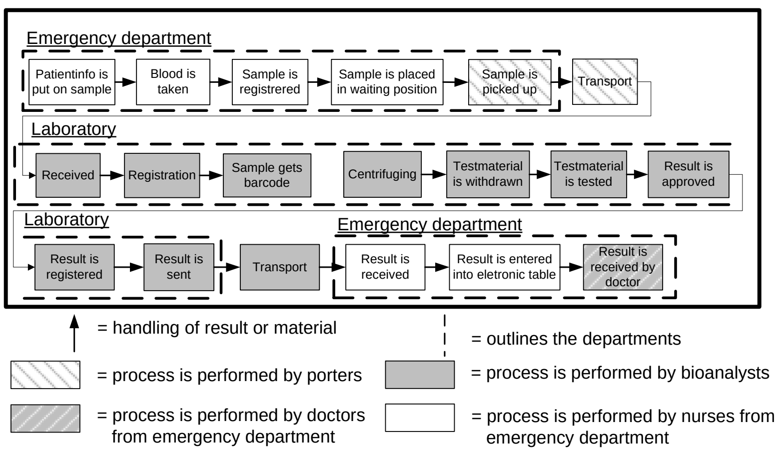

Figure 2: Process map for the blood samples taken in the emergency department

The major purpose of this system is to secure that the emergency department can get a result as soon as possible, so the patient can be diagnosed as soon as possible and thereby start the treatment. As a result of this, the simulation will be concerned with the process from blood samples are taken until result is received in emergency department.

The second case is the blood samples taken at the wards (wards case). As a very important tool in the monitoring of patients conditions the doctors at the wards use blood test. Therefore each morning biomedical analysts from the laboratory will go to the different wards and draw blood samples from the patients that the doctors require. The previous day doctors at the wards decides which patients needs to have blood samples taken, and this information is given to the laboratory, that makes blood glasses with labels ready for all the patients. There are approximately 140 patients that have blood samples taken. The processes involved in blood samples taken at the wards are shown in figure 3.

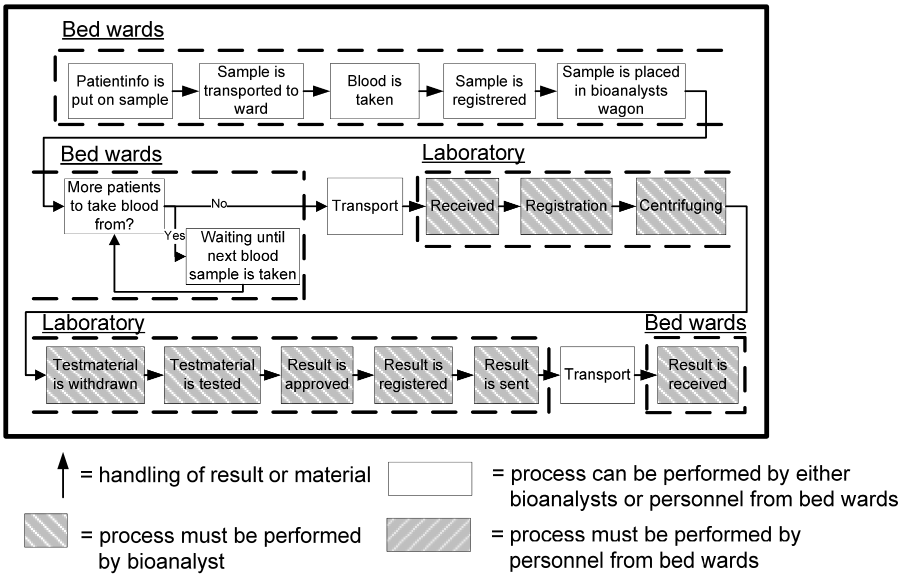

Figure 3: Process map for the blood samples taken at the wards

The major purpose of this system is to secure that the samples are transported as fast as possible back to the laboratory, because too long waiting time can have an undesired effect on the result. Further because of the great amount of samples being analysis, there is a risk of blood samples queuing up in the laboratory.

The hospital consists of 25 different wards where blood samples are taken. The wards are placed within four major parts of the hospital each consisting of two floors. These 4 parts consists of respectively 4, 6, 6 and 5 wards. Further there are 4 additional wards at two different locations.

Data collection

The data used in constructing the two simulations were based on data extracted from the hospital information systems, and from on-site observations of the time spent performing different processes. Further blue prints of the hospitals were used.

- Data extracted from database
    - Arrival of patient from January through March in the emergency department.
    - The time spent from a sample is put onto the conveyor system until the blood analysis data is ready and can be approved.

    - The amount of patients having blood samples taken from each of the wards.
    - Amount of time for taken blood test for each of the wards.
    - Time spent when finishing and leaving a ward.
- On-site observations and interviews:
    - Time spent drawing blood samples at different times of the day, and for different types of patients.
    - The velocity of personnel walking around the hospital.
    - The amount of time spent in each of the waiting positions.
    - Time used when waiting for the elevator and transportation time of elevator.
    - Time it takes to take the elevator.
- Blue print of hospital:
    - Layout of the different floors at the hospital with exact distances.

Simulation construction

The simulation approach used in this research is discrete event simulation. This is due to the many interdependent parameters with a randomly determination, and the tool used has been ProModel.

ProModel gives the opportunity of making a visual simulation of the system, and thereby the possibility of presenting the model to the health care personnel and get a validation of the construction of the model.

Both of the simulations models had focus on the throughput time of the systems, but the start and end times for the simulations were differently based on the differences of the systems. For the emergency case the time spent from a blood sample has been drawn in the emergency department until the result is received again in the emergency department was measured. Further focus was on determining whether any queuing occurred in the system. In the wards case the time from samples are drawn until samples are returned to the laboratory was of interest, as well as the distribution of sample arrivals in the laboratory.

The amount of resources used for each of the different technologies has been decided using the simulation. The decided amount of resources have been chosen when an increase in resources will not lower the throughput time with more than 10 %.

The variable input is the amount of nurses working in the emergency department and the amount of patients in the emergency department.

In both simulations all process times are described using normal distributions.

Results

For the emergency case the major time consumption was experienced during the transportation process between the emergency department and the laboratory, and during the analysis of the blood samples. The analysis of the blood samples is highly automated, so it was determined that it was not possible at the moment to change this process, and therefore the focus was on the processes happening from the blood sample is taken until the analysis is started.

The following technological changes were identified as suitable for performing the process in terms of the quality requirements set up by the hospital, and the physical layout of the hospital. The changes were made into scenarios and a simulation model was constructed representing each of the scenarios.

1. Using two robots to transport the samples between the waiting position at the emergency department and the waiting position at the laboratory.

2. Using a pneumatic tube system to transport the blood samples between the emergency department and the waiting position at the laboratory.
3. Using a pneumatic tube system to transport the blood samples between the emergency department and the laboratory. The samples will be received by a robot that places the blood samples in the conveyor system that is connected with the machines performing the steps of the analysis.

Further it was discussed whether it was possible to move the laboratory or the emergency department so there would be no transportation between the two departments. This was considered as not being possible, and is therefore not a scenario that is explored.

For the wards case the major time consumption was experienced when blood samples have been taken at the beginning of a blood taking round, and is transported with the biomedical analyst during the following part of their route.

The following technological changes were identified as suitable for performing the process in terms of the quality requirements set up by the hospital, and the physical layout of the hospital. The changes were made into scenarios and a simulation model was constructed representing each of the scenarios.

1. Using three AGVs to transport the samples between the wards and the laboratory.
2. Using a pneumatic tube system to transport the blood samples between the wards and the laboratory.
3. Using four porters to transport the samples. The porters goes rounds to the wards every 45 min, and picks up the samples that are ready and transport them to the laboratory.
4. Using three porters to transport the samples. The porters are called upon when blood samples are ready to be picked up.

Testing the scenarios

Each of the scenarios was tested to determine the average and maximum time. The average time is determined as the average throughput time of all the test runs. The maximum waiting time is calculated as the maximum throughput time obtained for the scenario in any test run.

Scenario	Average	Maximum
Current	87 min	118 min
AGV	74 min	103 min
Pneumatic	60 min	86 min
Pneumatic and robot	51 min	80 min

Table 1: Throughput time (in min) from blood samples are taken at emergency department until result is received in emergency department

Scenario	Average (% change compared to current)	Maximum (% change compared to current)
AGV	-15 %	-13 %
Pneumatic	-31 %	-27 %
Pneumatic and robot	-41 %	-32 %

Table 2: Change in throughput time compared to current situation

Table 1 shows the results obtained from the simulations of the different scenarios for the emergency case, and table 2 shows the change of time between the different scenarios and the current situation.

The simulations shows, that either using AGVs or pneumatic tube system will decrease the throughput time both in terms of the average and the maximum. If the hospital decides to implement the pneumatic tube system the potential decrease is 31 % for the average throughput time and 27 % on the maximum time. The hospital can also decide to install a robot that receives the blood samples at the laboratory and the decrease will be 41 % for the average throughput time and 32 % for the maximum throughput time.

The difference between the average throughput time and the maximum throughput time for the alternative scenarios is primarily due to the construction of the simulation. The different process times have been described using normal distributions, resulting in some extreme situations where the process time of all the processes are in the highest part of the bell curve.

The big difference in terms of the current situation is a combination of the processes being described using normal distributions. Blood samples taken in the current situation can however also experience two different extremes in terms of transportation, the samples can be picked up by the porter right after the being taken or it can take up to 30 min.

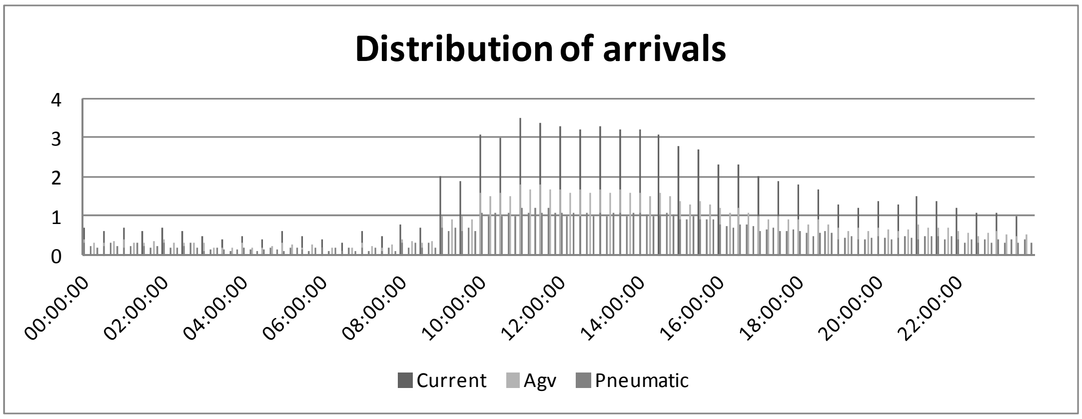

Figure 4 – Distribution of arrivals of blood samples at the laboratory for the emergency case using different scenarios.

Changing the means of transportation will result in a more even distribution of arrivals at the laboratory. The histogram shows that the amount sample in each arrival be approximately halved changing the current situation to using AGVs. The amount of samples with each arrival will also be lowered changing from AGVs to a pneumatic tube system. This is due to the increased amounts of transportations. Because the histograms are constructed using patient data from three months, the arrivals are not whole numbers.

Scenario	Average	Maximum	Spread in arrivals
Current	66 min	134 min	1 hr 23 min
AGV	55 min	110 min	1 hr 54 min
Pneumatic	43 min	116 min	1 hr 51 min
Porters going rounds	47 min	142 min	1 hr 22 min
Porters called upon	68 min	128 min	1 hr 49 min

Table 3 – Throughput time (in min) from blood samples are taken at the wards until samples are received in laboratory and the spread in arrivals

Scenario	Average (% change compared to current)	Maximum (% change compared to current)
AGV	-17 %	-18 %
Pneumatic	-35 %	-13 %
Porters going rounds	-29 %	6 %
Porters called upon	3 %	-4 %

Table 4 – Change in throughput time compared to current situation

Table 3 shows the results obtained from the simulations of the different scenarios for the wards case, and table 4 shows the change of time between the different scenarios and the current situation.

The simulations show that there is a big potential in changing the current procedure of the transportation. The biggest potential in terms of the average throughput time is using a pneumatic tube system that will decrease the average by 35 %. The largest decrease in maximum throughput time is obtained by using AGVs which will decrease with 18 %.

One of the results obtained from the simulation that stands out, is the high maximum throughput for the "Porters going rounds" scenario. This has the explanation, that at some wards the porters have just passed on their rounds, when the biomedical analyst has finished taking samples at that ward, and the samples will therefore wait a very long time, from they have been drawn until they reach the laboratory. Further some of the high maximum throughput times are due to extraordinarily high intake of patients at some of the wards on certain days.

The scenario with the largest spread is shown in table 3. The spread shows that "AGV" scenario has a spread of 1 hour 54 min, whereas "Porters called upon" and "Pneumatic" has respectively 1 hour 51 min and 1 hour 49 min. All of these scenarios perform better than the current situation which has spread of 1 hour 23 min.

Discussion

This paper explores the possibility of using simulation to address the outcome of operational changes in a health care setting. Hospitals are large complex institutions, and it is almost impossible to make simulations covering this complexity. However focusing on only one small part of the hospital, it has proved possible to make a simulation that draws a believable picture of the actual situation. This has been secured by getting the hospital personnel to validate the obtained results. It is however not possible to validate whether the simulations concerning the other scenarios are accurately. This challenge has been addressed by using the experience of other health care institutions who have been working with the proposed technologies.

Although it is important to have a narrow focus when creating a simulation like the one presented in this paper, it is however also important to be sure that all essential aspects have been addressed. How the different departments are connected to one another and how they influence each other, is very difficult for a person outside of the hospital to fully comprehend, with the risk of missing important influences in the construction of a simulation model. Validating the concept and the construction of the simulation model with the hospital personnel has been taken as the approach to handle this obstacle.

Constructing simulations that showed the daily work of health care personnel in a computer model was a new and interesting experience for the personnel at the hospitals. After the initial scepticism from the personnel, they were impressed with the opportunities in simulation models. It was however very important to include the personnel in the phase of coming up with new technologies. The personnel had some very clear ideas and perceptions on the usability of the different technologies. As a consequence some of the results surprised the personnel, but having used the simulation model as the mean of calculating the results, convinced the personnel of the validity.

Aside from exploring the possibility of using simulation in health care setting, the aim of the simulation was to provide two hospitals with an empirical basis for deciding whether to make changes to the current setup. The results from the simulation has been adopted by the hospitals and included in the decision process of determining whether changes should be made to the systems. It is important to state that the simulations were a supporting tool, and the major analysis on whether or not to make the changes was a financial analysis. Both of the hospitals have decided to go ahead with implementing the pneumatic tube system, as a result of the simulations and the financial analysis.

The research only focused on the effect of changing the technology used in performing a process. It is however possible that there is a big potential in using the same technology and merely rethinking the logistical system. Also the full potential of the technologies might not have been obtained in the simulation. This is due to the possibility of modifying processes according to the new technology, which has not been exploited as part of this research, but definitely will be interesting in relation to the implementation of the technologies.

It is important to state the results obtained in this research are only applicable to the cases involved. It is however possible for other hospitals to use the approach described in this paper to test which solution would be the optimal for them.

Conclusion

The research presented in this paper showed that it is plausible to use simulation models as an approach to address operational changes in health care settings. Constructing the simulation model used in this research was a new approach at dealing with logistical challenges in healthcare settings.

Using a simulation gave the hospital managers insight into some problems that they didn't have on beforehand, and it showed some problems that were not considered as problems. It opened up the eyes of the hospital managers of the possibilities of using simulation in this setting. It gave the hospital managers a basis that they had not used before in terms of making their decision in terms of verifying the effect of managerial changes. It was very easy to make changes to the system and the simulation showed its value as an idea generation for the hospital.

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Paper 6

P6: Identifying the Potential of Changes to Blood Sample Logistics using Simulation

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ORIGINAL ARTICLE

Identifying the potential of changes to blood sample logistics using simulation

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Abstract

Using simulation as an approach to display and improve internal logistics at hospitals has great potential. This study shows how a simulation model displaying the morning blood-taking round at a Danish public hospital can be developed and utilized with the aim of improving the logistics. The focus of the simulation was to evaluate changes made to the transportation of blood samples between wards and the laboratory. The average- (AWT) and maximum waiting time (MWT) from a blood sample was drawn at the ward until it was received at the laboratory, and the distribution of arrivals of blood samples in the laboratory were used as the evaluation criteria. Four different scenarios were tested and compared with the current approach: (1) Using AGVs (mobile robots), (2) using a pneumatic tube system, (3) using porters that are called upon, or (4) using porters that come to the wards every 45 minutes. Furthermore, each of the scenarios was tested in terms of what amount of resources would give the optimal result. The simulations showed a big improvement potential in implementing a new technology/mean for transporting the blood samples. The pneumatic tube system showed the biggest potential lowering the AWT and MWT with approx. 36% and 18%, respectively. Additionally, all of the scenarios had a more even distribution of arrivals except for porters coming to the wards every 45 min. As a consequence of the results obtained in the study, the hospital decided to implement a pneumatic tube system.

Key Words: *Computer simulation, efficiency, laboratory management, laboratory routines and automation, specimen collection and transportation*

Introduction

Blood samples are vital in diagnosing and monitoring patient illnesses and diseases. Blood samples are used extensively at hospital wards, and daily blood-taking rounds, where biomedical laboratory technicians go to the wards to draw blood from patients, are used. At Danish hospitals, procedures are implemented for wards with hospitalized patients to report which patients need to have a blood sample taken on the next blood-taking round. This information is given to the medical laboratory technicians, and daily at 08:00 h, a major blood-taking round starts, where the medical laboratory technicians will come to the ward and draw the ordered blood samples. When the technician has finished taking all the blood samples, he/she will bring them back to the laboratory for testing. The results from the tests will then be sent electronically back to the wards.

Performing the blood-taking rounds in this manner constitutes two different problems. The first problem is related to the prolonged time from when the sample is taken until analysis is initiated. Due to the importance of blood samples in the treatment of patients, it is of utmost importance that the results from the analysis are completely accurate. There are many different factors affecting the quality of the blood samples. Preanalytical errors account for nearly 60–70% in a modern laboratory, and some of the errors are attributable to mishandling procedures during transportation of samples from blood-sampling facilities to the laboratory [1]. For example, some plasma proteins and enzymes are inherently labile and should be protected from prolonged sample transport at extreme temperatures.

The second problem is experienced at the laboratory. Because the blood-taking rounds are initiated

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simultaneously and the medical laboratory technicians take samples from many different patients, there will be a large intake of blood samples in certain periods and a smaller intake in other periods.

In the following study, the aim was to address these two problems. The problems were addressed using discrete event simulation, and the following research questions guided the study:

1. How can a discrete event simulation model be constructed in order to represent the current situation at the hospital?
2. What effect will be obtained when changing the procedure of performing the blood-taking rounds?

The simulation therefore acted as a guiding and validation tool for the hospital managers in order to determine whether it was feasible to change the current procedure.

The case

The case involved in this study is Hvidovre Hospital, a major hospital in the Copenhagen area of Denmark. In addition to the clinical problems mentioned, the current approach is unacceptable from a logistical point of view. The problem is related to the samples drawn at the beginning of a blood-taking round that are transported back to the laboratory, once the round is finished and not immediately after being taken. When applying the current procedure, it is theoretically possible to deliver the blood samples to the laboratory approximately 20 min after they are taken, but due to the current procedure the average time is more than 1 h.

The hospital consists of four different 'houses' that are six-stories high and all connected with a large two-story high corridor. In this way, the hospital has a logistic challenge as the walking distances within the hospital are long.

The laboratory is located on the fourth floor in one of the 'houses', and all the wards with hospitalized patients are located on either the fifth or the sixth floor in each of the four 'houses', and with some additional patients at either ends of the corridor. The hospital has a total of 25 different bed wards included in the blood-taking-rounds.

This layout, together with the procedures, gives the basic outline for the simulation (see Figure 1).

The blood samples in focus for this study are normal blood samples. The hospital has two different groups of blood samples, normal and STAT samples. Normal samples are transported in the manner explained, whereas the STAT samples are transported directly after they are taken from ward to laboratory. STAT samples constitute less than 1% of the total amount of samples taken on the blood-taking rounds and are therefore not considered in this study.

Methodology

Based on the challenges and considerations presented by Hvidovre Hospital, a discrete event simulation model was constructed, focusing on the transportation process involved in the blood-taking rounds.

Why simulation

Simulation is the imitation of the operation of a real-world process or system over time [2], and can be related to different operations within industry, service and healthcare [3]. Computer simulation is a

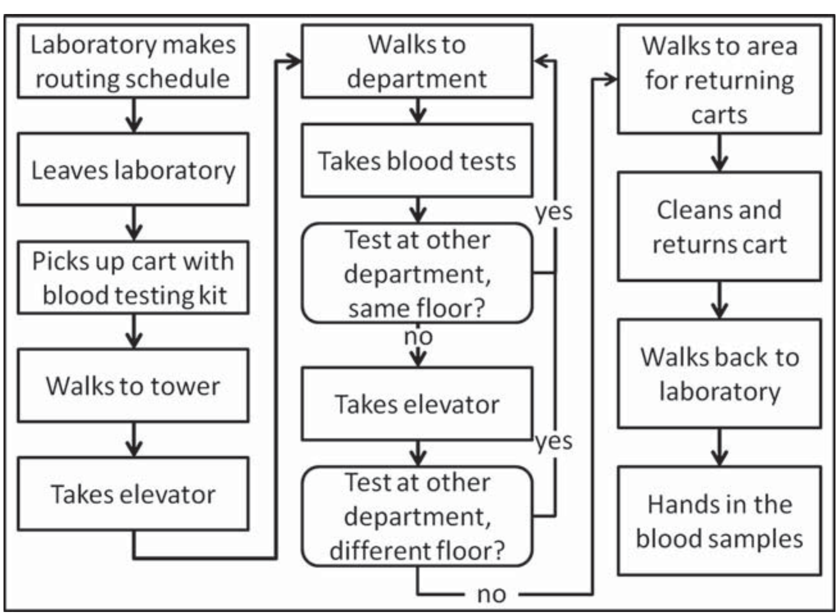

Figure 1. Process map of blood-taking rounds.

tool that allows the modeler to construct a model imitating a real-world system and thereby gives the possibility of conducting experiments in order to estimate the effect of changes to the real-world system [4].

The use of simulation can support many decisions in healthcare [5,6]. Examples are layout design [7,8], capacity planning [9,10], and scheduling [11,12]. As a consequence, the use of simulation and quantitative modeling in healthcare services has become widely used within the last couple of years [13].

Using simulation gives a number of benefits. It is possible to construct experiments without actually making changes to the system, and thereby it is possible to estimate the consequences of making the changes. Additionally, simulation can be made much faster than real-life experiments. As a consequence, simulations give the opportunity of testing many different alternatives quickly, rather than just testing one alternative at a time.

In this study, discrete-event computer simulation was used. Discrete-event systems represent systems where one or more phenomena of interest change value or state at discrete points in time rather than continuously with time [14]. This type of simulation is especially well suited for this type of study which has many interdependent parameters with a randomly determination [15].

The simulation tool used in this study was MedModel, a simulation tool constructed specifically for simulation within the healthcare sector [16].

The following approach was used: (1) A model of the current situation was created, and the magnitude of the problem analyzed, (2) different solutions to the problem were identified, and (3) the solutions were tested in order to identify which solution was the best.

Input to simulation

In order to generate a simulation that most accurately described the current situation, the following set of information created the basis of the simulation:

1. Layout of the different floors at the hospital with exact distances.
2. Laboratory technician's approx. walking speed.
3. Waiting and transportation time for elevators.
4. Time for taking a blood test at each ward.
5. Time spent when finishing and leaving a ward.
6. When a medical laboratory technician finishes his/her round of blood samples, they will help drawing the blood samples at other wards.

Changing the procedure of transportation

Four alternative scenarios were tested that were all based on the procedure outline presented in Figure 1: Automated guided vehicles (AGVs), pneumatic tube system, and two different types of porter scenarios. A de-central solution using point-of-care equipment at the wards was further considered, but it was, however, decided infeasible, due to too high costs involved in the acquisition, the higher cost per test, and problems in relation to the calibration of the point-of-care equipment.

The alternative scenarios were based on the simulation constructed for the current situation. For each of the scenarios, information regarding how the procedure was performed and how the different technologies worked, had been acquired and estimated. The information was acquired based on interviews with the personnel at the hospital, combined with the experience of the technology used and transportation means from other settings. Furthermore, different amounts of resources were tested for each of the scenarios in order to determine what amount gave the best result. The method applied for finding the optimal use of resources was by determining when an increase in resources would not decrease the time from sample when the sample was drawn until it was received at the laboratory with more than 10%. For example, using three resources instead of two would decrease waiting time from 1 h 30 min to 1 h 25 min which was equivalent to a decrease of 5.6%. Using two resources was therefore the best solution.

AGV

The first alternative technology tested was the use of automated guided vehicles (AGVs). AGVs are small mobile robots equipped with software that enables them to drive around the hospital without guidance from humans. The AGVs can pick up blood samples at the wards, transport and deliver them to the laboratory.

This solution is flexible, and the AGVs can be programmed to run different routes if problems occur with the current route. Using this technology, it is important that the blood samples are kept locked during transportation, thus ensuring that blood samples are not destroyed or removed from the AGV. Furthermore, it is important that there is a close monitoring of the AGVs in case of a breakdown. If these considerations are fulfilled, it is estimated that the quality of the blood samples will be equivalent to that of the blood samples transported in the current situation. In terms of resources, the AGV scenario was tested on the use of 1–5 AGVs.

Pneumatic tube system

The second alternative technology tested was the use of a pneumatic tube system to transport the blood samples from the wards to the laboratory. At the

Table I. Time from blood samples are drawn until they are received at the laboratory for the current situation (hr:min).

Date	23/8	24/8	25/8	26/8	29/8	30/8	Average
AWT	01:15	00:57	01:06	01:02	01:09	01:07	1:06
MWT	01:59	01:47	01:45	02:07	02:14	01:55	1:57

AWT, average waiting time; MWT, maximum waiting time.

departments, a sending station would be installed and at the laboratory a receiving station would be installed. Blood samples are transported through the tube from the sending to the receiving station. The blood samples are placed in the sending station like bullets in a gun, and the samples can therefore easily be placed in a queue.

The pneumatic tube system is not flexible. When the system has been installed, it is an extensive task to move the system to another part of the hospital. There are some doubts about the quality of samples transported by the use of a pneumatic tube system. Hastrup et al. [17] have, however, shown that sample transport by a pneumatic tube transport system did not induce changes to haematological, biochemical and coagulation components exceeding what is caused by routine courier transport. Furthermore, the influence of tube transportation on haemolysis parameters like the Potassium, Lactate dehydrogenase and Haemolytic index were tested and found to have no significant impact as compared to samples centrifuged within 10 min after sampling and transfer of the plasma to the laboratory.

Three different scenarios were tested. The first scenario tested had tube systems on each floor and tube systems for the wards at the end of the hospital, resulting in 10 tube strings in all. The second scenario contained one string for each house and a string for each end of the hospital, six strings in all. The last scenario only had strings to the houses, meaning that the samples taken at the wards at the end of the hospital were transported back by the biomedical laboratory technician, resulting in four strings in all.

Using porters for the transportation

The last two scenarios used porters as the mean of transportation. The first possibility was somewhat similar to the use of AGVs. The porter would come to the ward and pick up the blood samples and transport them back to the laboratory (Porter [call]).

The second possibility was to have porters walk predetermined routes every 45 min (Porter [45]). The porters would then pick up blood samples along these routes that had been taken when they came by the ward.

Using porters is a very flexible solution, since the porters can easily change routes and procedure. The quality of the blood samples is kept at a high level, since the porters are educated in transporting hospital goods and items. In terms of resources Porter (45) was tested for 2–5 porters and Porter (call) for 1–5 porters.

Testing each of the scenarios

Each of the simulations was tested based on data gathered at the hospital during six different days, using the amount of blood tests from each day, and how much time was spent taking each blood test. The six days were the weekdays in the period from Tuesday (23 August 2011) to Tuesday (30 August 2011), since no blood-taking-rounds are performed on Saturdays and Sundays. The hospital considered the schedule from this week as a normal week, showing a good representation of the workload. In order to compare the different scenarios, the hospital presented three parameters that should be used for evaluation in terms of determining how suitable the given scenario was:

- Average waiting time (AWT): The average time from when a blood sample was drawn until it arrived at the laboratory.
- Maximum waiting time (MWT): The maximum time from when a blood sample was drawn until it arrived at the laboratory.

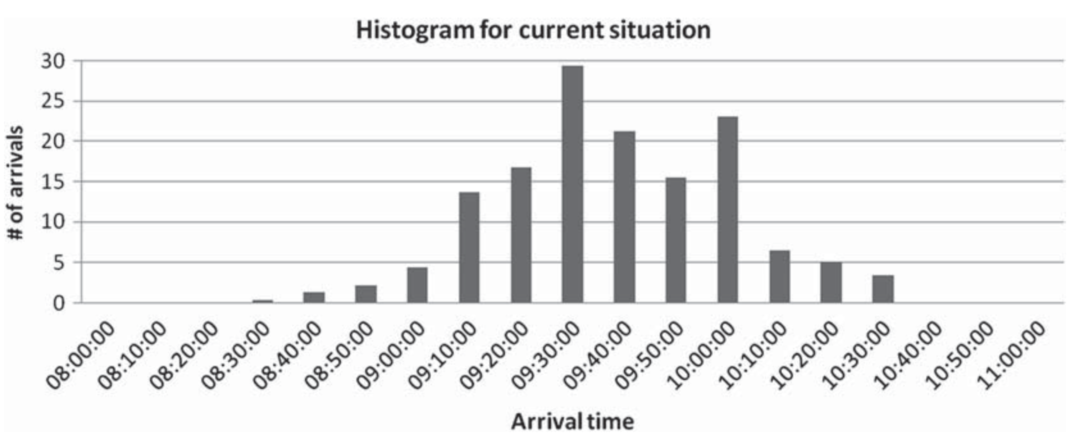

Figure 2. Histogram displaying the distribution of arrivals for the current situation.

Table II. The results for the automated guided vehicles (AGVs) scenarios.

Scenario	1 AGV	2 AGV	3 AGV	4 AGV	5 AGV
Distribution	(11:06, 68)	(9:52, 36)	(9:31, 27)	(9:28, 27)	(9:27, 26)
AWT	2:18 (N/A)	1:12 (47.8%)	0:55 (22.8%)	0:52 (6.0%)	0:51 (2.5%)
MWT	4:11 (N/A)	2:12 (47.1%)	1:40 (24.5%)	1:38 (2.6%)	1:33 (4.5%)

AWT, average waiting time; MWT, maximum waiting time.

- The distribution of arrivals of blood samples in the laboratory. The distribution of arrivals was displayed as histograms, and the mean and standard deviation of the histograms was calculated as well. The mean was calculated as the mean time of all blood sample arrivals at the laboratory. The standard deviation was calculated as square root of the average of the squares of the difference between the arrival times and the mean of the histogram.

Validation of results

Working with simulation always raises concerns in terms of validation and verification. Does the simulation present a realistic model of the real system? In the present case this was addressed by having a very close collaboration between researchers and personnel at the hospital. All the input and output parameters was discussed and decided by the researchers and the personnel from the hospital. The working procedures of the medical laboratory technicians were studied by the researchers, and a flowchart of the processes was verified by the personnel. Additionally, experiences and information regarding the alternative scenarios was acquired from national and international settings.

The verification process contained two steps: (1) Examining the results from the simulation and comparing with data extracted from databases at the hospital; and (2) discussing and validating the results at meetings with the Department of Clinical Biochemistry.

When the simulation model representing the current situation was approved, the work with the four other scenarios started. At regular meetings with the hospital the results from the different scenarios were presented, verified and validated. At the meetings with the Department of Clinical Biochemistry, the head of the Department, two medical laboratory technicians and the IT-administrator were present. In this way, the simulation model, the data from the model, and the procedures were verified by all the organizational levels involved.

Table III. Results for the pneumatic tube system scenarios.

Scenario	4 strings	6 strings	10 strings
Distribution	(9:19, 27)	(9:18, 24)	(9:14, 24)
AWT	0:43 (N/A)	0:41 (4.0%)	0:36 (12.4%)
MWT	1:36 (N/A)	1:36 (0.2%)	1:25 (11.8%)

AWT, average waiting time; MWT, maximum waiting time.

All process data was gathered from the hospital, and normal distributions were created for all processes; 25 runs were performed for each simulation, and the average results from the runs were used making the results more accurate.

Results

In the following section the results related to AWT and MWT are presented for each of the scenarios, as well as the distribution of arrivals.

Current situation

For the current situation, the results are presented in Table I. There was a slight variation in the average and maximum waiting time during the week. The average waiting time approximately followed the total amount of blood samples taken for each day, whereas the maximum waiting time was determined by single departments having a high number of blood samples on that specific day.

The histogram showing the distribution of arrival at the laboratory is presented in Figure 2. The histogram shows the number of arrivals in 10-min intervals between 08.00 and 11.00 h when all blood samples had been handed in at the laboratory. The histogram for the current situation had a mean of 9:38 and a standard deviation of 22.7 min.

AGV

For the AGV scenarios, the results presented in Table II are obtained. The distribution was denoted as (mean, standard deviation). The mean time was indicated as (hr:min) and the standard deviation as (min). The AWT and MWT were indicated as (hr:min) and the reduction comparing one scenario to the other was in percentage.

Pneumatic tube

Table III shows the results obtained for the pneumatic tube scenarios.

Porters

The results for the two different porter scenarios are listed in Table IV and V.

Table IV. Results for the Porter (call) scenarios.

Scenario	1 Porter (call)	2 Porter (call)	3 Porter (call)	4 Porter (call)	5 Porter (call)
Distribution	(10:31, 58)	(9:35, 31)	(9:23, 27)	(9:22, 26)	(9:21, 26)
AWT	1:45 (N/A)	0:57 (44.2%)	0:47 (17.8%)	0:46 (2.7%)	0:46 (0.0%)
MWT	3:15 (N/A)	1:49 (43.1%)	1:35 (12.5%)	1:31 (4.7%)	1:32 (−1.8%)

AWT, average waiting time; MWT, maximum waiting time.

Based on the criteria for selecting the optimal number of resources, three AGVs, four strings of pneumatic tubes, three Porter (call) and four Porter (45) were chosen as the scenarios that would be selected for further analysis. A comparison of the different scenarios is presented in Table VI.

Discussion and conclusion

In the study presented, it is shown that discrete event simulation is a powerful tool when testing what effect changes to a process will have. Different transportation processes of the blood-taking rounds were explored and the potential of four different scenarios estimated.

The simulation showed that the biggest potential was obtained by using a pneumatic tube system to perform the transportation process. The pneumatic tube system had a lower AWT than all the other scenarios on all of the days, and had a 36% lower average waiting than the current situation. The picture is, however, a little more unclear when it comes to MWT. The porter (call) scenario had the lowest MWT with a decrease of 19.4% compared to the current situation. However, both the pneumatic tube system and the porter (45) had an MWT of approximately the same.

The mean and the standard deviation for the scenarios showed that only the porter (45) scenario was less spread out than the current situation. The pneumatic tube system thereby secured a more even distribution of arrivals in the laboratory. Based on the results presented, the pneumatic tube system obtained the best results for transporting blood samples, and the hospital has started implementing a pneumatic tube system.

Besides addressing the two initial problems, it was estimated that a pneumatic tube system will have some additional positive effects. A pneumatic tube system will reduce the time from when a blood sample is taken until it is received at the laboratory whether the samples are taken by medical laboratory technicians or by personnel outside the jurisdiction of the laboratory. The pneumatic tube system also prevents samples from being lost or left unattended at a wrong place.

The hospital has estimated that the reduction in the average waiting time from when a sample is taken until it is received at the laboratory results in an equal reduction of the average length of stay for the patients. With a reduction of 23 min and an average of 142 patients per day, 54 h per day is saved, meaning that approximately two beds less are filled with patients. Based on these estimates, the hospital expects that the investment will break even within a year.

Using stochastically variables, time distributions and running replicas of the different scenarios, the discrete event simulation model is a reliable representation of the real system. In the study presented, the potential of using discrete event simulation is shown. Discrete event simulation is used as a tool for analyzing the current situation, and evaluating the effects of changing the procedures used in the current situation. This particular approach can also be used with great benefits within other areas of laboratory medicine. One example could be the procedures used when analyzing samples in the laboratory. Here, discrete event simulation could be used to investigate the potential of implementing new

Table V. Results for the Porter (45) scenarios.

Scenario	2 Porter (45)	3 Porter (45)	4 Porter (45)	5 Porter (45)
Distribution	(10:02, 21)	(9:50, 20)	(9:41, 22)	(9:22, 24)
AWT	1:32 (N/A)	1:18 (15.1%)	1:08 (12.1%)	1:01 (10.9%)
MWT	1:57 (N/A)	1:40 (13.9%)	1:36 (4.0%)	1:24 (13.5%)

AWT, average waiting time; MWT, maximum waiting time.

Table VI. Comparing the scenarios based on optimal number of resources.

Scenario	Current	AGV	Pneumatic	Porter (call)	Porter (45)
Distribution	(9:38, 23)	(9:31, 27)	(9:19, 27)	(9:23, 27)	(9:41, 22)
AWT	1:06 (N/A)	0:55 (16.4%)	0:43 (35.8%)	0:47 (29.4%)	1:08 (−3.0%)
MWT	1:58 (N/A)	1:40 (15.1%)	1:36 (18.2%)	1:35 (19.4%)	1:36 (18.3%)

AWT, average waiting time; MWT, maximum waiting time.

machines or making changes to the current set-up. The use of discrete event simulation in the approach presented in this paper can also be expanded to other areas within healthcare in general and hospitals in particular. For example, discrete event simulation can be used to make analyses of bed logistics at hospitals, determine the capacity need in emergency departments and the most efficient operation scheduling in the orthopedic department, etc. Discrete event simulation has a great potential in terms of making not only laboratories and procedures that laboratories are in charge of more efficient but also other parts within hospitals.

Limitation

The aim of the study was to investigate the operational effects of changing the procedure of the blood-taking rounds. It was not the aim to look at the economic implications of making such changes. The simulation should, therefore, be accompanied by an economic analysis in order to determine whether the changes are economically feasible.

The study did not consider what effects the change of procedure would have on other parts of the hospital that were not directly involved in the blood-taking process. For example, it was not considered what effects the change in procedure would have on the laboratory and the process of analyzing the blood samples.

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The health care sector in most developed countries is facing increased pressure due to the demographic development and the financial crisis. Health care managers are as a result focused on how to make health care institutions function in a more efficient manner, thereby securing more health care using fewer resources. At hospitals more than 30% of expenditures are related to various logistical costs, making the logistics an area with huge efficiency potential. However, hospital logistics are facing two problems. 1) Hospital logistics have to a large extent been dealt with using a departmental approach resulting in sub-optimised logistics. 2) Hospitals have not used technology to improve the logistical settings to the same extent as industry. Technology has primarily been used within clinical settings. There is therefore a large potential in using technology to improve the logistics.

This research is based on these considerations and presents an analytical model that can analyse the logistical system using a holistic approach, and explore the possibility of using technology to improve the current system. As a result of the research new technologies have been implemented in one case, and implementing technology is in the preliminary phases in other cases.

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